# Discovery

FEBRUARY 1953

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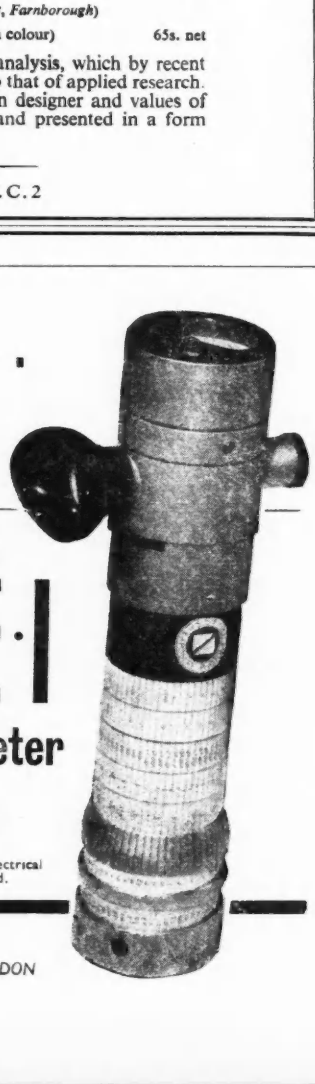

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# Discovery

THE MAGAZINE OF SCIENTIFIC PROGRESS

*Editor* WILLIAM E. DICK B.Sc. F.L.S. *Editorial Office* 244 High Holborn, WC1 *Telephone* Chancery 6518
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# THE PROGRESS OF SCIENCE

## ISONIAZID

In recent years a tremendous effort has been made to find a drug or combination of drugs effective against the tubercle bacillus. But in this line of investigation, disappointment is frequently encountered, for many of the drugs which have proved lethal to the bacillus cannot be used for treating patients afflicted with this insidious disease because of their toxicity to humans. Several drugs which have seemed promising when tried on a few cases have failed when given careful and systematic clinical trials on large numbers of patients. Up till recently streptomycin and P.A.S. (para-amino-salicylic acid) were almost the only two substances in which doctors had any faith, and even these had their limitations.

It was a year ago that the discovery of a new class of drugs with powerful anti-tubercular action was first announced. Initial trials had been made in treating tuberculosis with iso-nicotinyl hydrazine, and two related compounds.* It was reported that hopeless cases which had proved resistant to all standard forms of treatment had responded dramatically, and it seemed that a discovery of great importance had been made. The best results, it was then stated, had been obtained with iso-nicotinyl hydrazine. This substance now came to be produced on a fairly large scale and it gained the proprietary names of Rimifon and Nydrazid. Later the generic name *Isoniazid* was given to it.

The preliminary statements about it were cautious, and stressed that no true assessment of the value of iso-nicotinyl hydrazine could be made for many months. Furthermore, it was made clear that it was not and could not be the 'be all and end all' of tuberculosis treatment; it could not repair tissue damage and proven methods of medical treatment were still necessary. Nevertheless there were high hopes that isoniazid would turn out to be superior to anything yet known.

Two very vital questions needed to be settled before isoniazid could be accepted as representing a marked advance in the chemotherapy. Would it prove to be too toxic when administered over a long period, as it would have to be, and would the tubercle bacillus develop resistance to the drug? Such resistance had arisen in the treatment of tuberculosis with streptomycin, though this effect can be retarded by administering P.A.S. and streptomycin together. (The P.A.S. is given by mouth, the streptomycin by injection.) It is, therefore, on the elucidation of these two problems of toxicity and drug resistance that the acceptance of isoniazid as a satisfactory treatment for tuberculosis depends.

Isoniazid has now been manufactured in Britain for some time. Today there are over half a dozen different brands on the market.

The Medical Research Council lost no time in organising clinical trials of the new drug. These were on a far greater scale than any which the M.R.C. had hitherto conducted on an anti-tuberculosis drug, and thirty-nine hospitals took part in them. After six months an interim report was published in October 1952 on the first three months of the trials. That report revealed that the development of drug resistance is a very serious drawback to the use of isoniazid on its own as treatment for tuberculosis. Whilst initial results were good in every case, at the end of the first month bacillary resistance was found in 11% of cases, at the end of the second month this had increased to 52%, while at the end of the third month resistant bacilli had been found in 71% of cases. Toxicity of the drug was slight. Thus the committee responsible for conducting the trial were led to the conclusion that judging from short-term results isoniazid alone is a very effective drug, but not more so than the combination of streptomycin and P.A.S. The effect of combining isoniazid with other agents is forming the second part of the trial.

Further information has become available from other sources. One report from America states that resistance to isoniazid develops a thousand times faster than with streptomycin. But whereas streptomycin-resistant organisms grow as if the streptomycin were not present at all, isoniazid-resistant strains grow much more slowly in the presence of the drug.

* One of these was 1-iso-nicotinyl 2-isopropyl hydrazine, and the other was a glucosyl derivative of iso-nicotinyl hydrazine.

From one London hospital news has come of the use of isoniazid combined with streptomycin. Patients treated with isoniazid alone, whilst improving strikingly for the first eight or ten weeks, regressed rapidly thereafter; in contrast to those receiving isoniazid plus streptomycin, who maintained steady improvement over eighteen weeks, the period of the trial.

Most authorities are now unanimous in their view that isoniazid should not be used indiscriminately on its own for treating tuberculosis. When resistance develops, the final condition of patients may be worse than before the drug was given, and there is the added danger that isoniazid-resistant organisms may be transmitted to other patients.

Two lines of research are, therefore, currently being pursued. Tests are being made of the anti-tuberculosis power of a great number of compounds related to isoniazid in the hope of finding one that is superior. Already several active compounds have been synthesised in the U.S.A. The value of isoniazid in conjunction with other anti-tuberculosis drugs is also being studied, as mentioned in connexion with the M.R.C. trials, to find the most suitable combination.

One thing, however, is certain: in the initial stages of its use in the treatment of tuberculosis the attack of isoniazid is perhaps the most powerful of any drug yet discovered. Time alone will show just how valuable it is going to prove.

## FUEL CELLS

Primary cells that produce electricity by chemical action have been with us since the time of Volta, and many different sorts have been proposed and tried experimentally from time to time. A few of them have survived because of their practical convenience, such as the dry cell because of its portability, while others still lead a strange anachronistic existence in elementary text-books; but on the whole hardly any serious scientists have taken a general interest in primary cells for half a century.

One interest in primary cells, however, has maintained some continuity among scientists despite the universal use of the electromagnetic generator. It is an interest that has increased rapidly in recent years largely because of the looming problems of energy production. It is that of finding a cell that will consume natural fuels and so generate electricity more or less directly from these fuels. Such a cell is called a 'fuel cell'.

The argument behind this maintained interest is simple enough. The accepted and universal method of generating electrical energy in bulk usually involves three stages of energy-change: chemical energy to heat (usually of combustion), heat to mechanical energy by means of the turbine, and mechanical energy to electrical energy in the generator.

The efficiency of the second of these stages is limited by thermodynamic conditions, for the energy generated is equal to the heat available multiplied by a factor depending on the range of temperatures through which the working substance (steam) is put, and in the most efficient of modern steam-engines this factor is about 0·7.

In a primary cell, on the other hand, *all* the heat of chemical action is theoretically usable, and in addition there is no final stage of turning mechanical energy into electrical energy. So on theoretical grounds a primary cell utilising fuels should be more efficient than our usual generating methods using the same fuels. Furthermore, the overall efficiency of our usual generating methods is no more than 30%, so a fuel cell working at considerably less than full efficiency should still outdo the turbo-generator.

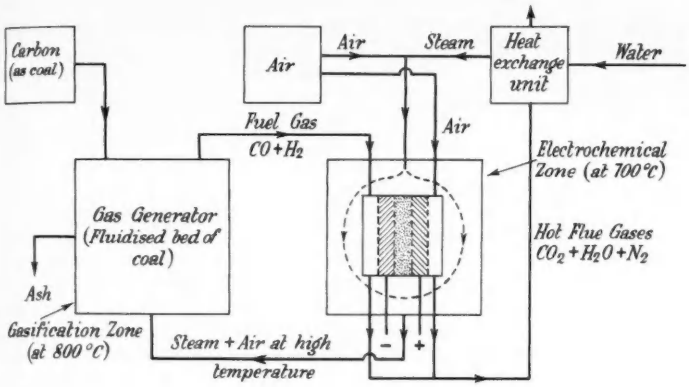
This is the simplified rationale. To apply it practically is another matter. Almost every primary cell is based on an oxidation of a metal, oxidation being a process of gaining proportionally more of an electronegative element or radical. (In this sense, not only is the change from carbon to carbon dioxide an oxidation, but so is the change, for example, from ferrous chloride, $FeCl_2$, to ferric chloride, $FeCl_3$.)

A fuel cell, therefore, should be based on the oxidation of carbon, i.e. coal. Such a cell, with carbon as one electrode and oxygen as the other, and an electrolyte in between, would be a *direct* one. No such simple fuel cell has yet been successfully produced, largely because carbon is not active electrochemically, i.e. it does not readily ionise. However, it is possible to make a type of direct fuel cell in which the direct products of the combustion of coal are used in the cell itself instead of carbon. Again, as long as there is negligible loss in the reactions, it is possible to use the fuel indirectly by using as electrodes, or else as renewers of electrodes, the products of chemical action involving the primary fuel. Such cells are *indirect* fuel cells.

It must be remembered that the aim in working on such cells is not merely to produce new laboratory cells but to design cells that can be used in batteries to produce current on a scale comparable to that of an electromagnetic generator. That is to say, the output is to be measured in kilowatt-hours; it is to be electricity on an industrial scale. Very high efficiency is obviously desired, and as an arbitrarily chosen standard for commercial working it has been suggested that a cell must produce a hundred milliamperes per square centimetre of electrode at an electromotive force of one volt. Cells producing less than this are not considered usable as rivals to electromagnetic generation based on coal fuel.

Obstacles to high productivity are not only the poor reactivity of carbon but also polarisation in the cell. This polarisation depends on gaseous diffusion that partially chokes electrodes, resistivity of the electrolyte to ionic movement, and secondary chemical reactions. To overcome these obstacles scientists have tried high temperatures (to speed up diffusion movements, increase reactivity, and decrease the resistivity), high pressures, where the electrodes are gases, and various other devices such as special electrolytes that are solid mixtures, and so on.

Some figures will indicate the sort of success so far achieved. There is the Bischoff direct cell devised in 1951 in Germany. This produces 0·5 milliamp./sq. cm. at an e.m.f. of 0·6 volt. The Davytan direct cell invented in Moscow in 1947 gives 20 milliamp./sq. cm. at 0·79 volt. The indirect cell invented by the same man gives between 25 and 35 milliamp./sq. cm. at 0·8 volt. No comparable figures are available for the cell patented by Gorin of the Pittsburgh Consolidated Coal Company, though it has been well spoken of and hailed as a step forward. Finally, there is the cell invented by F. T. Bacon at Cambridge in



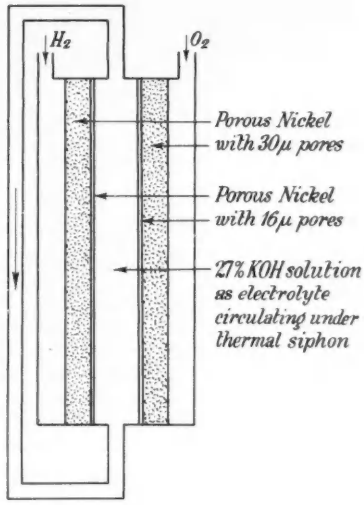


H2
O2
Porous Nickel with 30μ pores
Porous Nickel with 16μ pores
27% KOH solution as electrolyte circulating under thermal siphon

FIG. 1 (*above*). The fuel cell of E. Gorin (shown within the 'electrochemical zone' in this flow sheet) is designed to operate using hydrogen and carbon monoxide, prepared by reacting coal and steam. The cell has solid electrodes (iron plus ferric oxide) and the electrolyte is also solid.
FIG. 2 (*right*). The fuel cell designed by F. T. Bacon of Cambridge University runs on pure hydrogen and oxygen at 200° C.

1952 (British Patent No. 667,298). This gives at its maximum *650* milliamp./sq. cm. and even at a lower efficiency 330 milliamp./sq. cm. at 0·79 volt.

These figures speak for themselves. Of all the recent cells—apart perhaps from the Gorin cell, about which we know so little except its circuit and its short operating life—the only one which seems to be worth further attention is that invented by F. T. Bacon. It is an indirect cell in which hydrogen and oxygen are fed continuously through nickel partitions that are porous and immersed in an electrolyte—a solution of potassium hydroxide. The hydrogen and oxygen held in the porous nickel partitions constitute in fact the working electrodes. To prevent the electrolyte penetrating the porous nickel (which would result in the gases being kept out of the pores) the inner surfaces of the partitions have a coating of finer structure; the pores in this coating are so small that the liquid electrolyte cannot enter them.

The Bacon cell suffers from rapid corrosion of the nickel in contact with the oxygen, a problem that is being examined intensively now. Its chief projected use is for storage. Thus in off-peak periods a normal generator or a hydro-electric generator could electrolyse water to make the oxygen and hydrogen, which would be stored in gas cylinders and then used at peak-load periods to activate the cells and so add to the kilowatt-hour output of the generator.

In 1950 the British Association meeting was told that no satisfactory solution of the fuel cell problem was in sight, though the possibility of finding such a solution was not to be ruled out. Since then the Bacon cell has come on the scene. We can certainly look on this considerable achievement as a big step forward, but our optimism must be carefully restrained.

(The diagrams illustrating this note come from the Journal, *Direct Current*, Sept. 1952 issue, which contained a comprehensive survey of fuel cell research.)

## THE OLDEST TECHNICAL COLLEGE

That Britain has to improve its facilities for higher technological education is now accepted as axiomatic. The Government has announced in general terms its policy in this connexion, but has not yet committed itself to any very detailed proposals. It has, however, declared its support for the proposition that at least one institution of university rank "devoted predominantly to the teaching and study of the various forms of technology" should be built up. Secondly, it has in addition promised increased support to selected technical colleges.

Details about the first idea are most impatiently awaited, for the Government has said virtually nothing more about it since last summer when Lord Woolton stated that the Government favoured the organising of at least one technological institution of university rank. It has not indicated clearly whether this objective would be achieved by starting a new technological college, or by developing one (or more) existing institutions. The latter seems to be the more practical course, and this possibility we explored last November in these columns. We then mentioned the Royal Technical College of Glasgow and also the Manchester College of Technology, both of which have excellent records for the quality of the technological training they give and both of which could conceivably be converted into a technological university. It seems, however, that we did some injustice to the Royal Technical College, and we therefore wish to correct any wrong impressions which our note may have conveyed. Firstly, this college already has the status of a university college, and it has in fact been affiliated to Glasgow University for nearly forty years. Many of its full-time students register as internal students of Glasgow University; the last return of the University Grants Committee (for 1950–51) showed that 1097 students at the Royal Technical College were taking courses leading to degrees or associateships.

The college has its own Board of Governors and it

comes directly under the Scottish Education Department; the Glasgow Corporation does not have any control over it, a point of difference between Glasgow and Manchester, for there the City Council appoints the governors of the Manchester College of Technology.

Although its present title was adopted only in 1912, the Royal Technical College has a very long history. Indeed it is the college's proud boast that it is the oldest technical college in the world. Its origin can be traced back to 1796 when the Andersonian Institution or University received its charter from the city magistrates. It was named after John Anderson, the Glasgow University professor who endowed it, the principal intention behind his bequest being his desire to provide scientific education for skilled artisans. Almost the first special department to be started in the institution was a medical school, which became one of the most important in Britain. In the nineteenth century the college developed strongly the technological side, and it gained fame in particular for its departments of Technical Chemistry and Mechanical Engineering. In 1886 this institution was amalgamated with several technical colleges in Glasgow to form the Glasgow and West of Scotland Technical College.

The increase in the size of the student body coupled to the increase in variety of courses the college provided had resulted by 1939 in the need for extending its buildings. A new block of buildings to cost nearly £1 million is now in course of construction on a three-quarter acre site, and when this is completed it will house the whole of the Civil and Mechanical Engineering Department, leaving the rest of the departments with adequate accommodation in the old buildings.

* * * * *

The Manchester College of Technology has a comparable rank to that of the Royal Technical College. It provides technical courses for a large number of evening students (they exceed 6000), and in addition it functions as the technological faculty of Manchester University; the last published figure for full-time degree students was 880. The college has just celebrated its jubilee. Its activities over the past fifty years have expanded considerably, and the college has found its accommodation getting increasingly cramped. An ambitious extension programme is under way, and Manchester has good reasons for believing that when this is completed the college will be ripe for development into a technological university.

## MORE ABOUT PUMPING COAL

Last summer in this notebook we disclosed the fact that there was under consideration a proposal for constructing a Midlands-to-London pipe-line along which coal would be pumped in a stream of water (see DISCOVERY, August 1952, pp. 235–6). We made it clear that this was not just a bright idea with only a slim chance of ever being realised, but a scheme that represented an imaginative extrapolation made from past practical experience.

Since that note appeared a two-day conference on the hydraulic transport of coal has been held in London. Organised by the National Coal Board, this brought together scientists and engineers from the N.C.B. and the universities, and also from research stations (both British and French) and industrial firms that are interested in this subject. The Birmingham–London pipe-line was discussed, and there were papers dealing with other similar projects and with special aspects of hydraulic transportation methods.

It was clear from the outset that if the solid to be pumped is in a sufficiently fine form, there is no difficulty about handling it by this method. The operation of hydraulic sand-dredges (which dredge up the sand and deliver it along a pipe-line to a point a relatively long distance from the dredger) in rivers like the Loire has been carried on for a long time, and has been studied scientifically. The information collected has enabled M. Durand of the *Laboratoire Dauphinois d'Hydraulique* to state the conditions for economic operations. He told the conference that this was the cheapest available technique where high velocities can be achieved in the pipe-line, and the length of the pipe-line can be kept down to about a mile. The transport of fine coal over nearly 6 miles in Lorraine enables a significant prediction of cost to be made. This cost (which allows for plant depreciation) works out at about one penny per ton per mile and is attractive economically.

This French experience is consistent with the decision of Britain's Central Electricity Board to pump ash from the Rye House Power Station to worked-out gravel pits at Cheshunt, a distance of 3½ miles; a pipe-line for this purpose is now being constructed.

M. Durand's other conclusion is that, for successful hydraulic transportation of large particles, the pipe needs to be at least three times the diameter of the particles involved, if jamming is to be avoided. He is pessimistic, however, about long-distance transportation because it necessitates high-pressure pumping, and this means heavy wear on the pump.

The British engineers have not been deterred by M. Durand's forecast, and are going ahead with several ambitious schemes. For example, the East Midlands Area of the Coal Board has decided to install a plant to pump coal, at the rate of 100 tons an hour, from the top of a shaft in Markham Colliery to a central coal-washing plant 1000 feet away. This plant has been designed so that it can handle all sizes of coal up to 2 inches. In this scheme the Ministry of Fuel and Power is collaborating; the design of the coal pump is their concern, as is the design of the mechanism that will feed the coal into the pipe-line. Two firms have co-operated with the Ministry to perfect a pump-and-feeder design which avoids some of the anticipated difficulties.

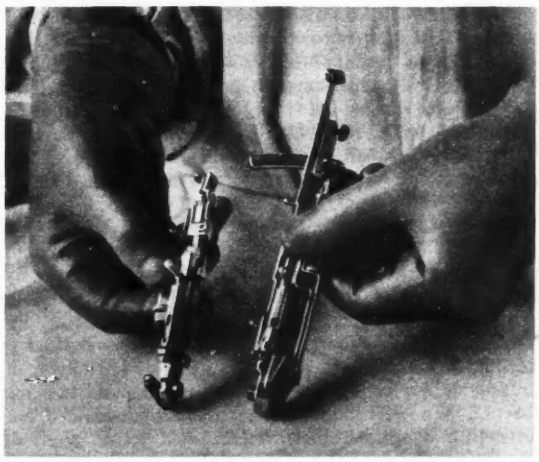
The Markham Colliery plant will provide valuable data about coal pumping which can be incorporated into the detailed plans for the Birmingham–London pipe-line. The latter project is now openly avowed by the Ministry of Fuel, which has stated that the eventual target is to move one million tons of coal a year along that 100-mile pipe-line.

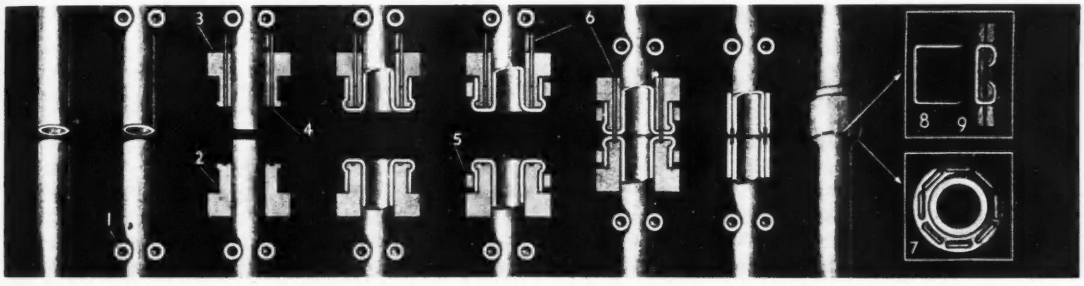
The theoretical discussions at the conference on the mechanism of the hydraulic transportation of large solids opened up even more exciting vistas for revolutionising the coal-fields. One real achievement which is relevant here belongs to Canada, where the Beauharnois Power Canal already has in operation an 18-inch pump that absorbs 1500 horse-power and can pump 120 tons per hour of rock

FIG. 3 (*right*). The machine for stitching blood vessels.

FIG. 4 (*below*). These diagrams show the mode of operation of the machine. In order to sew the damaged blood vessel, the ends of it are separated from the surrounding tissue. Clips (1) are put on each end of the blood vessel. Next the two ends of the blood vessel are passed through the bushes (2) and (3) of the machine. Bush (3) is charged with staples. The ends of the blood vessel are turned back over the bushes, to form collars; the inner layer of the blood vessel comes to form the outer surface of the collars. In order to prevent the collars from slipping off the smooth surface of the bushes, they are fixed with rubber rings (5). Both halves of the machine are brought together and a lever is pressed (by hand); the lever operates a tappet (6) which pushes the staples forward. The ends of the staples pierce the walls of both halves of the blood vessel and are then bent over; thus sewing the two pieces of blood vessel together. Both halves of the machine are now removed. One collar is next folded back to enclose the other collar. (This action involves a choice between the two collars; the decision is made according to the direction of blood flow in the vessel—in the illustration this flow is from top to bottom.) The clips are removed. In the join, contact between the inner surfaces of the two pieces of vessel is established; these surfaces knit together as a result of growth.

The two diagrams on the right show: (*bottom*) a view of the seam produced by the machine (7); (*top*) a staple before the operation (8) and after its ends have pierced the tissue of the blood vessel and been bent over to take the shape of a letter B (9).






which has been crushed down to pieces the size of 5 inches or less; the rock is thus transported a distance of 2000 feet by pipe-line. Transporting large coal along pipes therefore seems a reasonably good bet. But the working out of the size of pumps and pipe-lines required depends on more information being available about the frictional resistance to flow of these large particles in a liquid. This problem of two-phase flow is receiving considerable clarification through work being carried out in Prof. Newitt's Department of Chemical Engineering at the Imperial College of Science and Technology. The results from that investigation are being evaluated in large-scale experiments at the laboratories of the British Hydromechanics Research Association. On the basis of work carried out there, R. C. Worster has calculated that a 10½-inch diameter pipe would carry 100 tons an hour of coal 3 inches in size from pit bottom 1000 feet below the surface with 430 horsepower on a pump. The equivalent winding shaft required for lifting tubs by the ordinary method would have to be 16 feet in diameter instead of 10 inches. It only requires to link this proposal with a new American cutting machine to make possible a completely new technique for winning coal. This cutter was devised by a chemical firm, which has its own coal seams. It operates by transmitting signals to a surface control panel about the hardness of the material encountered. This enables the cutter to be guided into the softer coal band from which coal is continuously conveyed back. It has in its present form to be started from an outcrop of coal, but it appears to be the nearest answer to getting at narrow seams. One can imagine the use of this machine coupled with a system of hydraulic transportation for the coal cut by it, and one can begin to visualise a method which might be developed in the future for exploiting these difficult seams.

The National Coal Board has received many bricks since its formation. A bouquet is now due to them for the blend of imagination and realism which was shown in the organisation of this forward-looking conference.

## A SEWING MACHINE FOR STITCHING BLOOD VESSELS

A new surgical instrument is being produced in large quantities in the U.S.S.R. which, according to the Russian press, is the first instrument capable of stitching together mechanically the two ends of a severed blood vessel. With it, this operation can be carried out in a fraction of a second. The instrument has been used successfully on small blood vessels of 1 millimetre in diameter, and on a complete range of larger vessels. It has already been employed in many hundreds of operations on human patients.

A long article about this instrument has been published in the Russian journal *Tekhnika Molodezhi*. This gives not only a description of the instrument and how it works, but also the story of how it came to be developed by an aviation engineer, Vasili Gudov.

That story started right back in the autumn of 1941, when

Gudov, on his way to join the staff of an aircraft factory in the Urals, travelled on a hospital train filled with wounded soldiers. That journey sowed the seed of an idea—the idea of designing a machine which could put stitches in blood vessels. For the chief surgeon on the train had brought home to him the fact that many wounded limbs had to be amputated because the attempt to repair their severed vessels would jeopardise the patients' lives. Speed was of the essence, he was told, and only if the wounded blood vessels could be quickly rejoined could there be a hope of preserving a badly wounded limb.

It took him some five years before he succeeded in designing and producing a satisfactory machine. The way in which this brings together the two ends of a severed blood vessel and rejoins them by means of staples made of tantalum wire (which is completely harmless to human tissues) is indicated in the series of diagrams in Fig. 4. The task of testing and perfecting that machine he recognised as being beyond his powers so long as he worked single-handed, but after he had aroused official interest in it he was given all the facilities he required, and with the aid of a small team of engineers and surgeons he was able to carry his idea through the development stage and into practical use in hospitals.

The first test of the value of the machine was made by a woman surgeon, N. P. Petrova, who carried out a critical experiment in which a severed carotid artery in a dog was repaired with the aid of Gudov's machine. Many other experiments were made on dogs, until eventually the surgeons were so skilled in the technique that they felt ready to try the experiment of removing the leg from a dog and then restoring it. This difficult operation they carried through successfully. The blood supply to the rejoined limb was effectively restored, and in due course the dog made a complete recovery and returned to normal conditions of life.

According to the article in *Tekhnika Molodezhi*, Gudov's machine has now been used in many hospital cases, and it has made possible the effective repair of many limbs that otherwise would have had to be amputated. The article gives some surgical details which seem to justify the claims that are made for this instrument. It would indeed come as a real pleasure to learn in the near future that the Russians are sending specimens of this instrument abroad, so that international surgery could benefit from this invention.

# RESEARCH ON FATIGUE

D. C. FRASER
M.A., M.Sc.

Probably all of us who run cars have had occasion at some time to drive for a much longer period than we are used to. We then become uncomfortably aware of a number of rather unpleasant symptoms—stiffness in the muscles, cramp in the legs, pain in the back, eyestrain, headache and so on. If we observe our driving performance from time to time—or better still, have someone else observing it and making notes of important points—we may realise that we are slower in making some responses than we ought to be, or that we fail to notice a trafficator signal until it is almost too late, or that for quite long spells we drive at a faster speed than usual. This condition we call fatigue; we have all suffered from it, and we all agree that it is important.

We might expect, then, that a good deal of attention would have been paid to this phenomenon by those scientists who deal with the measurement of human performance and by doctors and industrial experts, and that a commensurate amount of reliable information would be available. It is quite true that fatigue in one form or another is continually being discussed or studied by different groups of people all over the world, but unfortunately we do not have very much to show so far for all this expenditure of breath and energy. Fatigue is but another example of those common phenomena, like the common cold, the problems of which often prove the hardest nuts to crack scientifically. It has proved surprisingly difficult to define fatigue in any rigorous way, and most people writing or speaking of the subject nowadays are careful to explain how they are using the word rather than what it means. We can, in fact, distinguish three main contexts within which fatigue is studied; these may be called respectively the *physiological*, the *functional* and the *subjective* aspects.

The physiological aspects of fatigue have been studied in considerable detail, and the information derived from this work is relatively clear-cut, but fragmentary. We can, for example, remove a piece of muscle from an animal, and cause it to contract repeatedly by the application of electric shocks. The contractions will become smaller and smaller until a stage is reached when the muscle no longer responds to stimulation. If we allow the muscle to 'rest', or wash it in a 1% saline solution, it will regain its power of contraction. This fatigue effect is due in part to the accumulation of chemical end-products, such as lactic acid, resulting from the chain of biochemical reactions associated with the contraction of muscular tissue. Normally these waste products are swept away by the blood. (It is interesting that certain symptoms of fatigue can be produced in a rested animal by injecting blood from a fatigued animal into it.)

If, instead of using only a piece of muscle, we experiment with a muscle to which a piece of nerve is attached, and stimulate the nerve electrically, we find that the muscle contractions diminish and finally disappear as before; if, however, we now stimulate the muscle directly, the contractions will reappear, but they will be less strong than before. It appears that the earlier loss of function in the nerve serves to protect the muscle from exhaustion.

When we turn to the consideration of the whole organism, the physiological picture becomes less clear. It is possible to demonstrate that waste products of muscular activity accumulate where there has been excessive physical activity, but little or nothing in the way of a chemical measure of fatigue has been so far observed as the result of less strenuous work. In particular, it has not proved

possible to find a simple physiological indicator of the fatigue resulting from prolonged intellectual effort, although subjectively this appears to be one of the most exhausting of human activities. In fact, measures of neuromuscular changes—oxygen consumption, blood pressure, heart rate, etc.—are really most valuable when we are approaching the limits of performance.

In ordinary working and playing we seldom approach these limits, and the fatigue most important to industry and the individual falls into the second class—the functional. Here we are concerned with objective measures, such as the falling-off in output or in performance, which we take to be indicative of fatigue developing. You might reasonably ask at this point if the subjective aspects of fatigue—feelings of boredom, lassitude and irritability, for example—are not the most important from the individual's viewpoint. Unfortunately, it is possible to get almost any kind of subjective judgment of fatigue going with the same objective performance, so that, while we should never ignore the individual's introspections on this matter, we cannot as yet derive much in the way of useful and consistent information from them. The rest of this article will be concerned chiefly with the functional aspects of fatigue.

At first sight, research into fatigue appears to be simple. One has only to devise a good test for fatigue, then apply it to the operator under a variety of conditions, and measure the change in performance. We might, for example, test the operator in the morning and then again in the evening after his day's work. In another experiment we might test him before driving a car, after driving for one hour, after driving for two hours, three hours and so on; this would give us a clear indication of how long it is safe to continue driving without a break. We could similarly test for the effects of different lighting conditions, or the effects of alcohol, on performance. A good, reliable test for fatigue would simplify the analysis of an enormous number of industrial, engineering and social problems. But no such test has yet been developed, although the timing test mentioned in the last section appears promising.

## FATIGUE IN FLYING

One fundamental problem in the devising of a suitable test for fatigue is the adaptability of human performance. Let us consider the case of the car driver who has been at the wheel for a long time. He may have reached a stage when it is obvious to the observer that his driving performance is impaired; he is making responses later than he ought to, or he is failing to notice signals from other drivers. But if we test him on a conventional psycho-motor test we shall probably find that he does almost as well on the test as he did before he commenced driving. His reaction to the novelty of doing that test tends to mask the fatigue effects resulting from a long spell of driving. Although this phenomenon has been known to psychologists for many years it is surprising how often it is rediscovered by some enthusiastic experimenter. I was told by a physician only the other day that he had devised a simple test of the speed of visual discrimination which he intended to use to measure the degree of fatigue produced in pilots flying long sorties of ten hours or more. He was astonished to find that his exhausted and bored pilots actually scored higher in the test after flying than they did when fresh.

It is appropriate to mention here one of the most thorough investigations into the nature of fatigue of this kind which was carried out during and after the war at the Psychological Laboratory of Cambridge University under the direction of Sir Frederic Bartlett. An experimental cockpit was built at Cambridge in which could be simulated all the major elements involved in flying an aeroplane by instruments. This was connected to a recording apparatus which kept a comprehensive and exact record of everything the pilot did. The cockpit did not itself move, but the instruments responded realistically to movements of the controls. Although there were certain differences from a normal aircraft, the tests, which took the form of an exercise in instrument flying, were accepted as reasonable by the pilots who were used as subjects in the experiment.

The subjects used in the experiment, all trained pilots, were given written instructions for four manœuvres together occupying ten minutes, repeated between intervals of straight and level flying.

The test usually lasted for two hours, although performance over longer periods was studied. The experimental flight was divided into spells, each of a quarter of an hour. There was a clock which the pilot could use at the end of each spell to check whether he was working accurately and with perfect timing. If, as sometimes happened, the pilot forgot to make this regular check, his performance would begin to deteriorate, especially after about two hours. But provided that he used the clock, and if he were keen, physically fit and skilful, he could continue for very long periods without any fall in the level of his performance. One pilot was in fact able to continue for twelve hours without a break (being fed as he worked), and at the end of the testing he was working as well as at the beginning.

## DETERIORATION IN TIMING

On the whole, the errors made by the pilots followed a definite pattern. They increased during the first half-hour, were at a maximum in the second half-hour, and then declined. The time for which the errors persisted did not increase at first, but later, as the number of errors declined, their size and duration increased. Most striking of all the findings was the deterioration in timing; and since the importance of this factor in all skilled performance is not always appreciated, I shall consider it in more detail.

If you have ever had the exhilarating experience of driving a golf ball right on to the green from the tee, or cracking a fast cricket ball from the bowler to the boundary, you can appreciate how perfectly co-ordinated the whole movement is, how precisely each step in the series fits into the whole pattern of movement, how beautifully the distance is judged—and how hard it is to repeat the same stroke exactly. This delicate, precise co-ordination of judgments and movements into a continuous smooth pattern is what is meant by timing. It is perhaps the most important factor in any skilled activity, and as Sir Frederic Bartlett has pointed out, it is the first thing to suffer as the individual becomes fatigued. It is not so much that the operator does the wrong thing as that he does the right thing at the wrong time. For example, when the operator

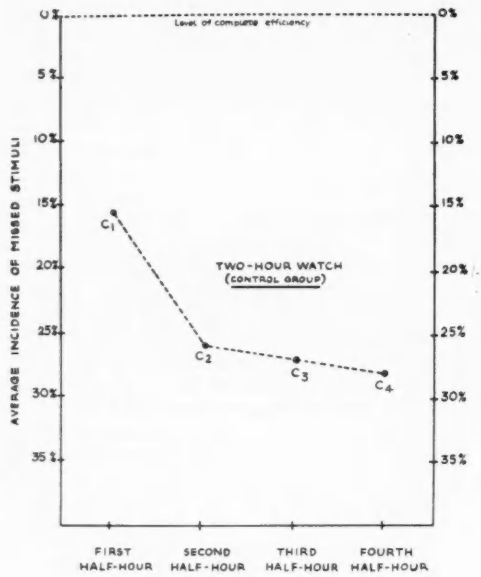



FIG. 1. The effects of a two-hour watch. Vigilance is reduced by fatigue; the reduction in vigilance is measured by the percentage of signals missed by the observers. Note the increase from 15% to over 25% after the first half-hour.

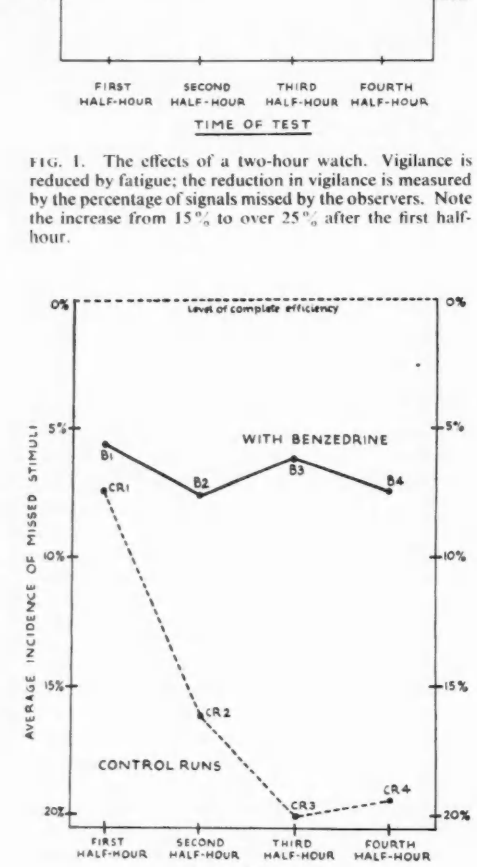



FIG. 2. The lower graph resembles that in Fig. 1. The upper graph shows how the observers retain their efficiency after taking benzedrine.

has to notice a changing signal,* he will often do nothing until a much bigger change has taken place than was necessary at the beginning; it seems as if the operator's senses have become less acute, so that they are no longer able to detect a difference which was previously appreciated without difficulty. If, however, we give the operator a special test, we usually find that his senses are able to make just as delicate and exact discriminations as at the beginning. What seems to happen is that there has to be a bigger change before the operator considers it worth while to do anything about it.

The danger at this particular stage of fatigue is that the operator does not usually know that he is waiting for the change to become really critical; he thinks that he is working just as well as ever. It is important that this stage should be fully studied in all skilled activities. If the operator knows that he is fatigued, and that as a result his performance is liable to deteriorate, he can make the necessary allowances to avert accidents. If you become consciously tired after a long period of driving, you can deliberately school yourself to drive more slowly, to take a longer time to come out of side roads, to pause every half-hour to take a short break, and so on. Perhaps the most critical stage of fatigue is that occurring when the performance is falling off and the operator has not recognised the fact.

A second symptom of fatigue which developed in the cockpit experiments was the failure to notice signals which required action only occasionally. Instruments such as the petrol gauge, which required to be reset at intervals, tended to be forgotten as the spell of testing went on. Actions to be made in response to signals lying outside the main field of attention also tended to be omitted.

Finally, as fatigue increases, the operator tends to become more and more conscious of sensations coming from his own body. You have almost certainly noticed that you can give your full attention to the speaker at the beginning of a lecture; but that after half an hour (or less if the lecturer is boring) you become conscious of the hardness of the seat, the heat in the room, the glare of the lights, and so on. A really well-delivered lecture is notable for the fact that chair scraping, shuffling and coughing are at a minimum. (It might indeed be practicable to measure lecturing skill by studying the intensity of random noise arising from a typical audience.)

## VIGILANCE TASKS

One of the most interesting attacks on the problem of fatigue has been in the field of watch-keeping situations. Here the scientists use the convenient term 'vigilance tasks'; these are tasks in which the operator has to maintain a watch for some specified signal or change in signals over a long period, and is not given information, direct or indirect, about any signals he has missed. This kind of situation was studied in detail by Dr. N. H. Mackworth during the war to determine the optimum length of watch for Coastal Command radar operators on anti-submarine patrol. It was characterised by five special features:

* Thus one of the observer's tasks was to watch a small needle, very much like the needle on instrument dials. Every so often the needle would jump a small amount, and the pilot had to bring the needle back to zero. As the test period continued, the error score in correcting the misalignment became progressively greater.

(*a*) Usually it was a matter of 'waiting for nothing to happen'. The anti-submarine searches very often drew a blank. There were also frequent alarms from, for example, Spanish fishing vessels in the Bay of Biscay, and the chance of an aircraft pilot agreeing to investigate a contact reported by his radar observer was only one in eight; there was no more than one chance in thirty that any such contact investigated would prove to be an enemy submarine.

(*b*) The radar operator usually worked in complete isolation except for some form of telephonic inter-communication.

(*c*) He seldom had any check on his working efficiency. If for any reason he became less alert than usual, no warning signal pointed this out.

(*d*) The object of his search was usually difficult to see on the radar screen. In the type of radar set then most widely used, the signal indicating a distant submarine was a small spot of light of poor contrast about 1 millimetre in diameter. This was viewed from a distance of about 12 inches, and appeared on a speckled and flickering background around which was sweeping a thin bright radial line of light.

(*e*) There was usually a time limit for effective action. If the echo from a submarine appeared for only a few seconds on the screen, the operator had to report this brief stimulus while it was still there; otherwise the contact might well be lost for ever, since the submarine would submerge on detecting the searching aircraft.

To study this situation in the laboratory, Dr. Mackworth used a 'clock test' for many of his experiments. In these the subjects sit looking at a black pointer 6 inches in length which normally moves like the second hand of a large clock in front of a white vertical surface. Every second the pointer jerks on to a new position, one hundred of these movements making up the full circle. There are no scale markings or reference points of any kind on the background. The subject is told beforehand that every now and again, at long and irregular intervals, the pointer will move twice the usual distance, giving the effect of an unusually large jump forward. He is to watch out for these movements and press a response key as soon as he notices one.

The graph (Fig. 1) shows the average incidence of missed signals in a group of 25 R.A.F. cadets who did the test for two hours. It is clear from this that operators tend to miss substantially more signals in the second, third and fourth quarters of the test. This suggests that a deterioration in vigilance occurs in such a situation after half an hour. This was confirmed by other experiments, and as a result it was recommended that the most suitable length of watch for a radar operator is 30 minutes. A number of other experiments were carried out by Dr. Mackworth using this test. One interesting result was that 10 mgm. of benzedrine taken by mouth one hour before the start of the test successfully maintains the initial level of accuracy over the whole two hours of the test (see Fig. 2). (Precautions were taken to guard against suggestion effects by using a control group which was given exactly similar lactose tablets; this group did not show the same effect as with the benzedrine.)

## EFFECTS OF NOISE

Although the original vigilance experiments were undertaken to answer a practical question, research on this type of task has continued in Cambridge after the war. An interesting variation of the task has been used by Mr. D. E. Broadbent. The apparatus here was designed to test the vigilance of subjects for visual signals appearing from a large number of possible directions and remaining visible until dealt with. The apparatus shown in Fig. 3 consisted of twenty dials similar to those of steam-pressure gauges; each of these had on it a mark above which the subject was told that the pointer on the gauge should not be allowed to rise. A mechanism selected and actuated various dials in turn so that these were made to indicate a level above the danger-mark at various intervals after the beginning of a watch. The time taken to notice this signal was recorded.

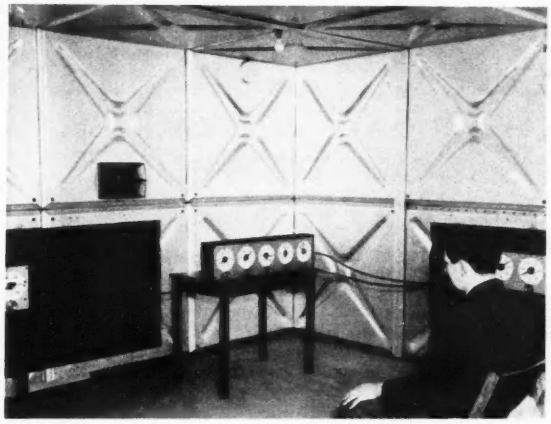


FIG. 3. The twenty-dials test.

These experiments gave some important information about the effect of noise on the performance of such a vigilance task. Many experiments have been made to study objectively the effects of noise on performance. But, although people complain about excessive noise, and feel that it must affect working adversely, it has not been possible to show any consistently significant effect. Sometimes subjects do better, sometimes worse, when they have to contend with noise, but frequently there is no measurable change. What Mr. Broadbent's experiments have shown is that there is a substantial and consistent impairment in the performance of vigilance tasks carried out in high-intensity noise (100 decibels); this impairment is shown by some subjects but not by others.

## INDIVIDUAL DIFFERENCES

So far we have been discussing fatigue generally. But there is an important side to the subject which we have still to consider—how far do people differ in their ability to resist fatigue? This question of individual differences in what might be called 'fatiguability' is one which affects anyone who has to select people for different types of job, and it is particularly interesting from the research angle. Obviously, if it proved possible to measure an individual's 'fatiguability', and if this proved to be fairly consistent under the same conditions, we could make fairly confident predictions about the factors likely to upset his performance after we have carried out a few tests.

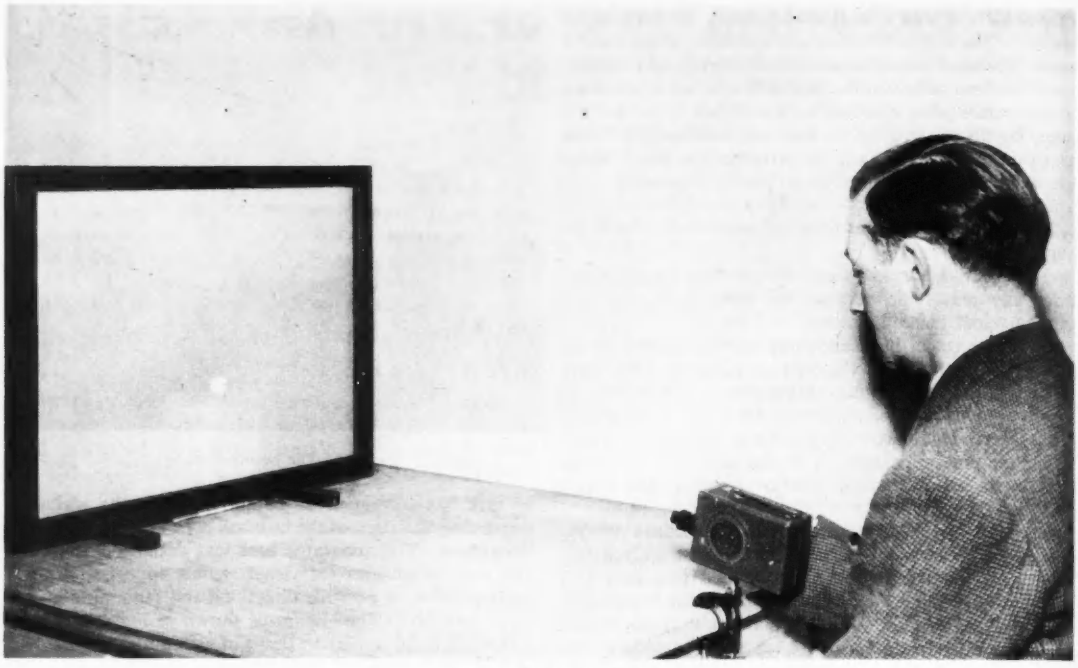


FIG. 4. The timing test.

From the subjective viewpoint, we do know that people differ widely in their ability to withstand fatiguing conditions before they complain about them. But, as we have already seen, we can have almost any subjective judgment of fatigue going with the same objective performance. How are we to separate the subjective factors—boredom, for example—from the objective changes in performance? Clearly this can be no easy job; and, in concluding with a brief note on my own work on the problem, I should like to stress how necessary it is to be cautious in drawing general conclusions from a limited amount of laboratory investigations.

The test used in this investigation embodies certain features of the vigilance task and also involves the characteristic we have seen to be so important in fatigue—timing. The administration of the test is rather complicated, but the basic task for the subject is quite simple. He has to pick out a certain kind of signal (in this case a circle of light) from a series of signals passing slowly across a screen, and to photograph this light-circle when it is exactly half-way through its travel.

The scoring of the test deserves special mention. Instead of measuring the subject's discrepancies from the true centre of the frame outlined on the screen, we use a mathematical index (called the *standard deviation*) which gives us a measure of the individual's variability of estimation. Under carefully controlled conditions, this standard deviation score has proved to be relatively consistent on repeated retesting of the same individual when he is fresh. Moreover, it usually rises quite markedly after a fatiguing activity, such as a prolonged spell of driving, or after a bad night's sleep. (It has also shown a rise after the consumption of several pints of beer, but I doubt if it would make a suitable test for the police surgeon to use.)

Unfortunately, the test itself is rather wearing, the scoring is complicated and the experimental conditions have to be carefully controlled. (I do not think, however, that an easier and shorter test would be capable of giving us reliable and effective results.) But it does give us a sensitive measure of fatigue of one kind, and should prove useful in the study of work conditions, and in the analysis of, say, driving fatigue as well as a research instrument.

(Much of the material discussed in this article is based on experimental work carried out by the Medical Research Council Unit for Research in Applied Psychology at Cambridge.)

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# THE ORGANISATION OF THE ANT COLONY

DEREK WRAGGE MORLEY
M.A., F.L.S.

Among the 15,000 species of ants which are known can be found many diverse forms of social organisation. Some ants live in vast colonies; the members of one single nest may number several millions. Others live in colonies averaging a bare dozen individual ants.

Most ant species have three different types of individuals, or *castes*: the male, the female (or queen) and the worker (or sterile degenerate female). But in some species there are no special queen ants and in some there are no workers. In most species of ants the males survive only until the marriage flight; then, after mating with the winged females, they are forbidden the nest and are left to wander about until they die. Yet in some species the male shares part of the work of the colony. A few hundred species have a fourth caste, the soldier caste, composed of large-headed workers that defend the colony and perform other special functions.

Some ants are hunters, some Goth-like nomads and raiders, some are harvesters, others herdsmen. Slave-makers, thieves, parasites, guest ants; vast empires of a thousand nests and minute colonies wholly contained within the shell of a beechnut: all these are found within the ant world. In fact, there is no general norm in the ant world where behaviour is concerned; one cannot cite a particular species of ant and describe its behaviour as a typical example of ant behaviour generally.

The primitive ant society, as found today in some relics of the distant part of this family such as *Amblyopone* from Australia, consisted of a few individuals sheltering together under a stone or in some protected hollow. Although *Amblyopone* (which belongs to the most primitive sub-family of ants, the Ponerinae)* has a worker caste, the members of it are little different from the queens which have lost their wings after the marriage flight. Both queens and workers go out to forage. Even the winged males sometimes play a part in the general work of the *Amblyopone* colony; moreover, they are also very similar structurally to the queens and workers. The queens are present in relatively large numbers compared to the proportion of queens to workers which is encountered in the societies of the higher ants. All told, the community may only consist of 20–50 individuals, of which about half to two-thirds may be workers and the rest females plus perhaps a few males (though the males live only a relatively short time after mating). Foraging is an individual activity in which there is little sign of co-operation. Each individual leaves the nest alone and seizes what prey it can, eating some on the spot and returning to the nest with the rest. The grubs are elongate, mobile and voracious creatures that largely feed themselves, grabbing the pieces of insect flesh that are scattered around by the returning foragers. They receive scant attention from the workers and queens and are rarely fed or licked by them.

* There are eight ant sub-families: the PONERINAE are the oldest sub-family of ants and the most primitive in both form and habit. The MYRMICINAE, the two-knotted ants, include both primitive and highly developed and highly social forms, including the Harvesting ants and Fungus-growing ants. The DORYLINAE are all nomadic Army ants of primitive ancestry which never make permanent nests. The DOLICHODERINAE, the Scavenger ants, link the Formicine ants to the Ponerine ants, and many of them form large colonies and live a highly developed social life. The FORMICINAE are the most highly developed of all ants, the latest sub-family to appear in the evolutionary tree; they have the most highly developed societies. The common black ant of the garden belongs to this sub-family. The other three sub-families, the CERAPACHYINAE, LEPTANILLINAE and PSEUDOMYRMINAE are all rare ants, confined to tropical and sub-tropical regions.

## REGURGITATION

None of these primitive Ponerine ants regurgitates food to their grubs. This is an important point because the mutual feeding of the grubs and the worker ants plays a vital role in the social behaviour of all the truly social ant species. The act of grub-feeding does not, for most ants, mean solely that the worker ant concerned regurgitates a drop of food to the pouting larva; the worker in its turn receives a reward. The larvae possess a gland situated close to their mouths, which produces small quantities of liquid. This liquid is exceptionally attractive to the adult ants. As the ant society developed this apparently rather insignificant gland can be seen to have come to play a

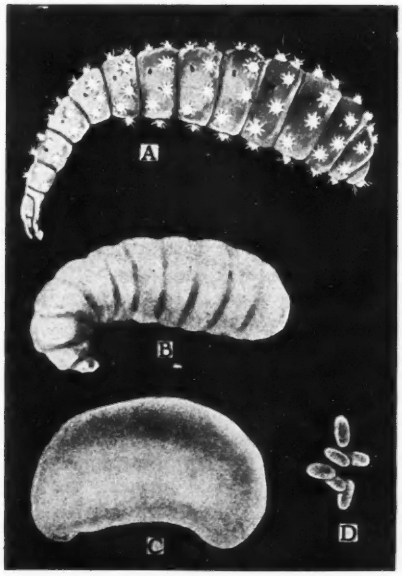


FIG. 1. ANT LARVAE: (A) The elongate mobile larva of the Ponerine ant *Lobopelta elongata* which feeds itself by grabbing food left beside it in the nest.

(B) The slightly mobile larva of the Myrmicine American harvesting ant *Pogonomyrmex molefaciens* has a well-developed gland for producing the secretions attractive to the workers.

(C) The immobile larva of the Dolichoderine scavenger ant *Tapinoma erraticum* is quite unable to feed itself and depends completely on the workers for its food. *(After Forel.)*

(D) is a cluster of eggs.

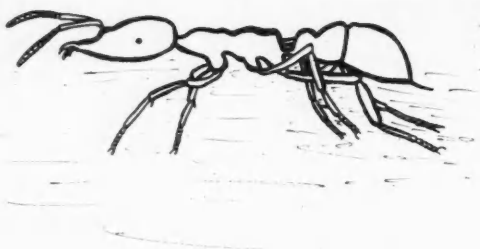

FIG. 2. *Amblyopone ferruginea.* A primitive species which has survived in Australia, it lives in small colonies comprising only a score or so individuals who leave the nest singly to forage for their own food. It is nearly blind, moves slowly and has a thick protective chitinous skin over the whole of its body.

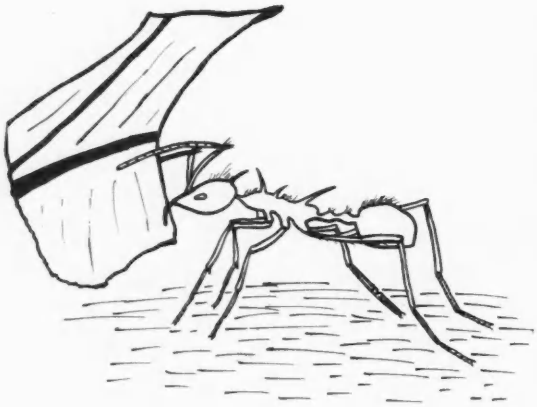

FIG. 3. South American fungus-growing ant (*Atta-fervens*) carrying a newly cut leaf back to the nest. In the nest the leaves are chewed into a mulch on which the fungus, which is the food of these ants, is grown. (*Adapted from Forel.*)

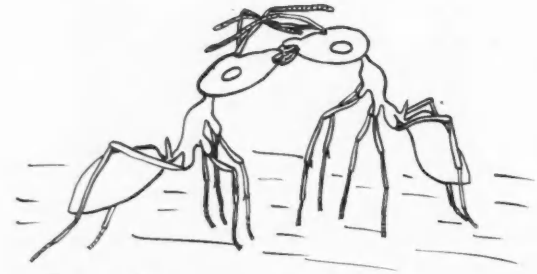

FIG. 4. A Formicine ant (*Acanthomyops*) regurgitates a drop of honey-dew to a nest-mate. The act of regurgitation is one of the most significant factors in both ant psychology and ant economy.

larger and more important part in the evolving pattern of social organisation. For the attractiveness of this fluid makes the grubs precious to the workers; one realises that the workers tend and care for the larvae with remarkable assiduity, not because they recognise them as their offspring in the way that mammals, for example, recognise theirs, but because the skins of the larvae are covered by this fluid. The queen ants are important to the workers not as queen mothers of the colony, but simply as the producers of large numbers of creatures which yield this desirable fluid. When a queen is barren she is no longer treated so kindly, so solicitously licked, so carefully guarded; in cruel fact, she is usually killed when she is no longer of any importance as a producer of the grubs which yield the delectable fluid. It is because of this fluid that the grubs are seized and hurried away in time of danger. It is because of the lack of these fluid-producing creatures that the queenless ant colony becomes lethargic and seemingly dispirited.

If a worker takes the place of a queen, as sometimes happens, and produces large numbers of larvae, then she is treated as royally as a queen, even though the larvae begotten by the fecund worker develop eventually into useless males instead of workers.

## REGURGITATION AND DIVISION OF LABOUR

It even seems probable that the development of the mutual regurgitation between grub and worker is the basis of a second major phenomenon of ant life—the mutual regurgitation of food from one adult ant to another. In any colony of Formicine, Myrmicine or Dolichoderine ants this regurgitation of food from the crop of one ant to another's can frequently be seen. In the ants of these three sub-families it is the basis of the division of the labour permitting a few to gather food for the many and yet ensuring the spreading of the food collected throughout the colony. The crop of the ant is a stomach in which no digestion occurs, and it is separated from the true stomach of the ant, in which the food is digested, by a powerful valve (the gizzard). The crop is capable of great distension and acts as a living food basket for the ant. When food is regurgitated the two ants concerned raise themselves high on their legs and stretch out their heads to their fullest extent. Then quivering with open jaws, the donor releases the drop of liquid food which rolls across the two pairs of opened mandibles into the mouth of the recipient. There can be no doubt that this act, repeated many times each day by all the multitudes of these ant colonies, represents something very important in ant behaviour. The close contact of one ant with another, the handing over and receiving of food, and the extreme physical tension of the posture assumed by both donor and recipient, must all combine to make it one of the most important elements of ant life. (If a psychologist of the dynamic school were to turn his attention to ant life, he would undoubtedly base much of his system of ant psychology on this act of regurgitation.)

The extent of this contact can be gathered by the fact that if a group of half a dozen yellow ant workers are fed on honey dyed sufficiently strongly with some different colour, say red or blue, so that it can be seen through their

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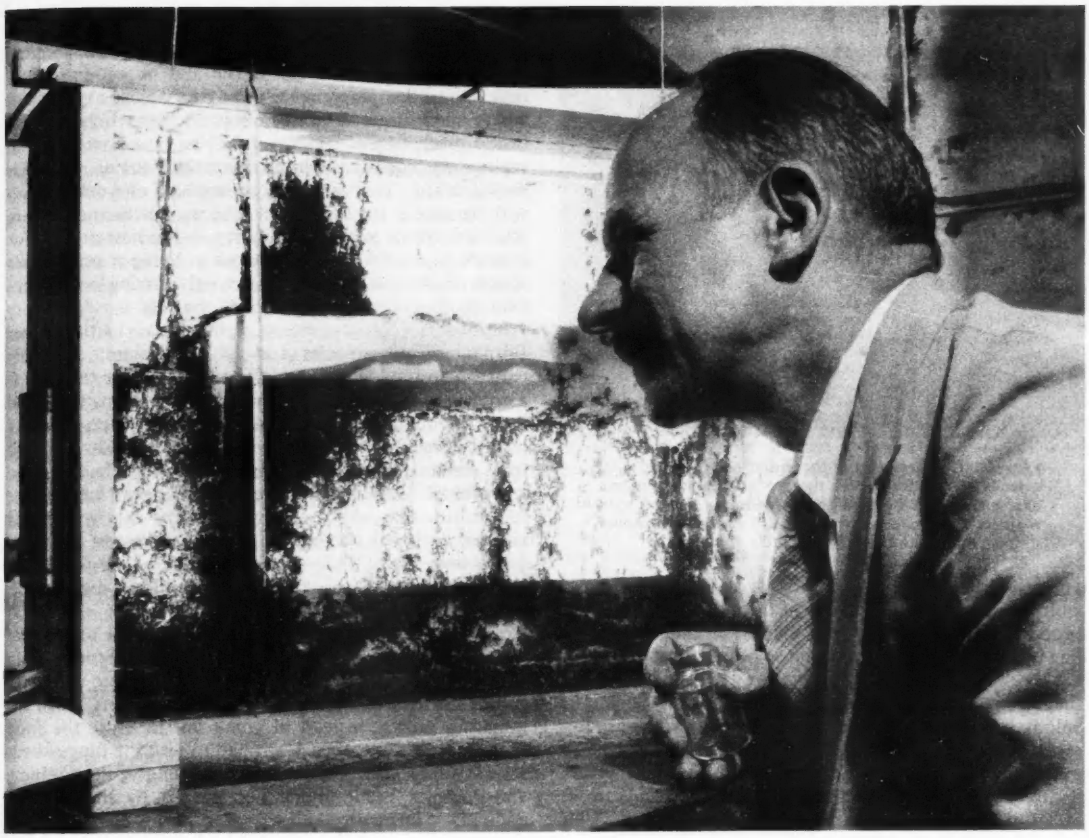
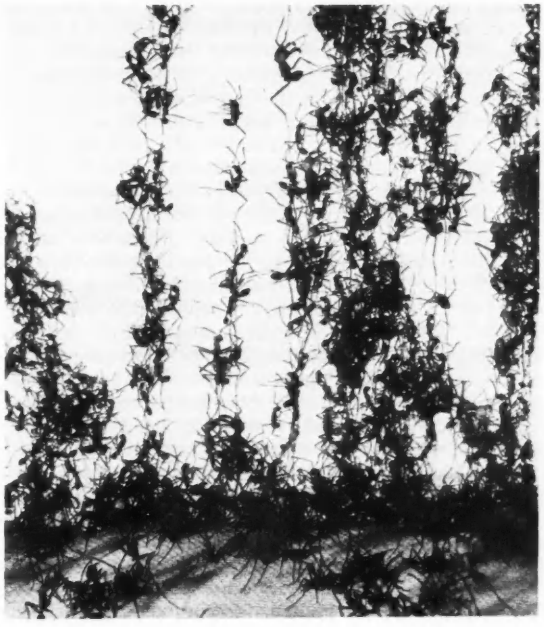


FIGS. 5 and 6. Dr. T. C. Schneirla, Curator of the Department of Animal Behaviour of the American Museum of Natural History in New York, watches a colony of South American Army ants (*Eciton*) forming a nest cluster and living ropes inside their observation nest. These ants never excavate a proper nest. Their colonies of 40,000 to 80,000 individuals remain only 2–3 weeks on the same site, living in a natural hollow or a rotten tree trunk while the queen lays her eggs. They then continue on their march for a further 2–3 weeks before forming another temporary bivouac during the next egg-laying period.



chitinous skins, then the whole colony of yellow ants, several thousand strong, would be seen to have red or blue abdomens 24 hours later. Experiments with radio-isotopes have similarly demonstrated the rapidity with which food gets shared throughout a colony. The passage of food throughout the colony by means of regurgitation is indeed a rapid and efficient process.

Except in the most primitive ants belonging to the Ponerine sub-family, these two habits—the licking of the grubs and the sharing of food amongst the workers—are found in all the ants in various stages of evolutionary development. The Ponerine ants do lick their grubs occasionally, but not often, and they take little care of them. If a primitive Ponerine colony is attacked, there is individual fighting in self-defence, but little care for the brood. The mutual feeding is likewise poorly developed.

Here then are two basic factors in the organisation of the ant society which carry with them two riders. The

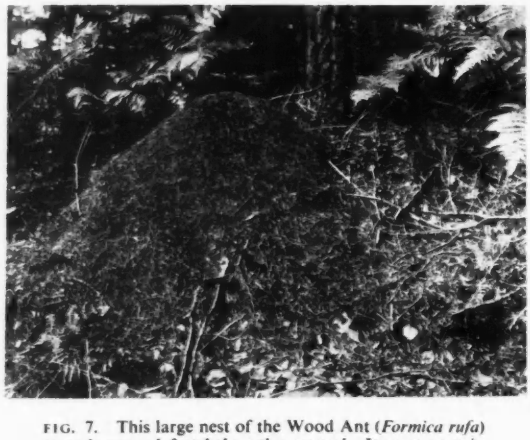


FIG. 7. This large nest of the Wood Ant (*Formica rufa*) extends several feet below the ground. It may contain nearly a quarter of a million individuals. Several such nests (often numbering from 6 to 10) are linked together to form a large and closely integrated commune.

attractiveness of the ant brood has developed *pari passu* with the increase in the fertility of the queen ants: the large brood of a fertile queen producing several thousand eggs a day is adequately cared for because of the attractiveness of the larvae. The eggs are whipped away to safety as soon as they are laid because they are potential grubs. If an ant colony is attacked, it is the eggs and larvae which are first seized and carried away by the defenders. The more fertile queen is more helpless and the attractiveness of her offspring ensures her the necessary extra attention and care: to be anthropomorphic, one might almost say she is stuffed with food rather on the slot-machine principle—more food put in, more 'goodies' come out.

The second rider is that the development of mutual regurgitation between the workers made possible the development of a system of division of labour in the colony. An ant can carry back to the nest in its jaws more food than it needs for its own use, but not greatly more. An ant making several foraging journeys could therefore carry back enough food to feed several other ants, but if reliance had to be placed on food carried in the jaws alone, then most of the colony would of necessity be engaged in foraging throughout the hours of daylight. This is the case in the Army ants (Dorylinae) of the tropics of the Old and New World. A colony of these ants usually consists of about 80,000 adult individuals, and between them they have to catch half a gallon of insect food each day. They do regurgitate food one to another, but not to the same extent as the more highly developed social ants. They are nomads, who never settle in one spot for more than 3½ weeks and they never build a proper nest. It would in fact be physically impossible for them to do so, because they would be unable to spare the workers for the foraging force. Solely carnivorous ants like these are never great city founders. To build and maintain a large ant's nest requires a large labour force. The availability of this labour force depends on the efficiency of the food-getting per individual forager. The number of workers released for other activities depends on the number supplied by each foraging worker. A large nest involves continual cleaning of the chambers and alleyways, it involves continual repair and improvement. It necessitates the maintenance of territory close at hand for which adequate food can be obtained. It involves a large brood producing a constant supply of new population to replace the equally constant drain by natural and accidental death. This means large numbers of workers busy with the care of the brood and queens. Furthermore, there must always be a large population in the nest at rest, for ants do not work all day, but when living a normal life spend much time asleep or seemingly dozing or perhaps sunning themselves on the roof of the nest.

This degree of complexity of life found in the higher Formicines, Myrmicines and Dolichoderines, can only exist where food is grown in the nest, or where the crop is actively used as a basket carrying considerably more food than the forager needs for itself, and where there is also a highly developed system of mutual regurgitation of food from one ant to another. For even if each ant had to go to a source of food in the nest each time it was hungry, the labour situation in the colony would be nearly as badly affected as if each one had to go outside the nest to forage for its own food.

There are some ants which do grow food within their nests—these are the fungus-growing *Attini* of South America. Here the labour situation depends on exactly the same factors as when the food has to be brought into the nest, but the ants which go out of the nest to forage collect leaves with which to make the mulch on which the fungus is grown, instead of going out to bring the food itself into the nest. If each ant had to visit the fungus beds several times each day when it felt hungry, the foraging and complex nest-building necessitated by the need to maintain a large population, brood and well-conditioned fungus beds, could not be achieved. Only the spread of food by regurgitation makes it possible. If an adequate supply of mulch is not forthcoming the fungus crop will fail; at the other extreme, if the fungus beds are not adequately tended the fungus may spread throughout the nest and destroy the colony. The maintenance of the happy medium involves work, which could not be done if each ant had to spend time going to fetch its own food.

The harvesting ants of the sub-tropical regions also carry much of their food into the nest in the form of seeds which are stored until they begin to germinate. When this happens the ants cut off the rootlet that emerges, and bring the seed out into the sun to dry. The starch in the seed turns into sugar and gives the ants a source of food within the nest. But to house the seed, complicated galleries must be built and a large labour force must be available to move the seeds within the nest if conditions become too moist. At the same time a large force must be out foraging if enough seeds are to be collected. Husk-cracking is carried out by a separate caste: these correspond to the soldier caste and take no other part in the activities of the colony except to crush the hard husks of the seeds and to rush to the colony's defence in case of attack; they too must be maintained with food. Few individuals in the colony therefore have the time to go direct to the food chambers to feed, and without mutual regurgitation the whole social system with its complex division of labour would fail.

The extreme case of maintenance of an *élite* caste is seen in the obligatory slave-makers, the Red Amazon ants (*Polyergus*). These creatures not only do not forage, they cannot even feed themselves. Their slaves, belonging to a different species (usually the Large Black ant, *Formica fusca*) must regurgitate food to them or they would starve, for their scythe-like jaws prevent their picking up or sucking in food unless it is actually placed in their mouths.

In this case the *Polyergus* go out to get slaves, which in turn get the food to regurgitate to them—the slave-makers' only contribution to the economy of the colony is to ensure the supply of slaves. The slaves must then build and maintain the nest and tend the *Polyergus* queen (no slave queen is allowed) and brood, and go out to forage for enough food for all the slaves engaged in these tasks (as well as for themselves) and for the *Polyergus* workers. They need to be efficient foragers and circulators of food.

This then is the bare bones of the organisation of the ant colony, a story that is too vast to tell in detail. The mechanism by which this division of labour is decided and made to tick is another part of that story, but basically it is equally simple. It depends on no language, nor on any higher command or direction. One ant just responds to a simple stimulus, say an internal one like hunger, or an external one like the pouting of a grub for food, the soliciting of another hungry ant, or the jamming of a passageway, or the smell of rotting matter. The ant sets out to forage, feeds the grub or other ant, or goes out to seek food for it; repairs the nest or removes the rotting matter. Other ants not already engaged in other tasks copy it. The stimulus lasts until the task is completed or the individual ant's response to it is sated, or until it is attracted away to a more strongly demanding stimulus. Learning ability here plays a part, especially in the higher social ants where it is better developed, for ants learn to forage in special places or to do tasks different from one another and often better. But the mechanism is one of inherent simplicity, of awaking to activity and responding to instinctive patterns presented by events, yet responding in a way that is conditioned by copying other ants and by learning. Yet without regurgitation between ant and grub, grub and ant, and ant and ant, there could be no division of labour in the ants as seen today, and no large social communities of these most successful of insect kind.

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# THE MILITARY COLLEGE OF SCIENCE

MAJOR E. H. W. BANNER

*M.Sc., M.I.E.E., F.Inst.P.*

The application of science to military problems is no new thing, but the contribution of science to the solution of such problems has grown in extent and importance, until today it is generally recognised to be an indispensable and decisive factor in defence preparations. The vital part played science in modern war was vividly demonstrated in the Battle of Britain. Had it not been for the early warning which radar gave of the approach of enemy bombers, the R.A.F. would have been unable to put sufficient planes in the air to neutralise each and every raid, and to win that battle. It was the radar chain which tipped the balance in our favour, and but for this scientific development the gallantry of 'the few' would have been in vain and the battle would have been lost. This is a most striking example of the decisive effect which the introduction of a scientific technique can have on the result of a military operation, but it is no isolated example.

The British Army is fully alive to the revolution science has wrought in all phases of warfare. It has accordingly taken steps to ensure that it has sufficient officers and men with the right kind of training to cope with the problems of modern scientific warfare.

Scientific or technological training is required in the army for four purposes: (*a*) instruction for the actual user of the weapon, instrument, etc.; (*b*) maintenance and repair; (*c*) development; (*d*) for general knowledge. The first requirement postulates that even the supposedly non-technical infantry officer needs to have a knowledge of scientific principles to be able to instruct his troops in such matters as the use of their weapons, explosives, range-finding equipment and fire-control instruments; there is a still greater need for scientific training in the technical corps—the Royal Engineers, Royal Corps of Signals, and the Royal Electrical and Mechanical Engineers. The second item, maintenance and repair, has more obvious application to R.E.M.E. and to the Royal Corps of Signals and some other corps responsible for first-line repair, or repairs in their own workshops or on site. Those who are concerned with the development of new weapons and equipment clearly need to have good scientific knowledge.

It is not sufficient for science to be regarded as something which arises only in the design, development and production of military equipment. It is perhaps still true that the final link in the chain of human operators does not usually need to have any scientific training—for as far as possible the job he has to do is made a semi-routine one of 'following the pointer', in the fire control of guns, for example, or aiming a rifle, etc. Between these extremes there are many stages where varying degrees of scientific knowledge and experience are necessary.

At the top level, close co-operation between scientists and engineers on the one side and military officers on the other is essential when new weapons have to be designed to fill a specific need. Generally the need is seen by the army and put up to the technical experts, but on occasion a scientific principle is discovered or developed by a scientist working outside this field, who sees it has potential military applications and brings these to the notice of the

appropriate military experts. Radar is a good example of the way a non-military technique (for the beginning of radar was the use of radio-echoes to fix the range of clouds, etc., in meteorological research) can be applied to a military need. A more normal example demonstrating how new technical equipment is developed can be found if one considers the everlasting battle between gun and armour; the experts responsible for gun development are continually striving to outdo the other side, and out of this continuous battle of development come many scientific problems which require investigation before technical advances of military significance can be made. There is, of course, close co-operation nowadays between the army and industry, since military establishments can only produce a model or a single prototype of a new piece of equipment, leaving industry to take over at an early stage and develop the weapon and bring it into a form suitable for large-scale manufacture.

One organisational link in the chain connecting the scientists with the military is the Army Operational Research Group. This type of research was developed during the last war to bring the scientific approach to bear as directly as possible on the most practical military problems; it proved effective as a means of assessing, for example, the military value of weapons and other equipment and of finding out how improvements could be made. In operational research investigations, the reactions of the military users were all-important. In some cases the scientists found that a new weapon is disliked by the troops from some purely personal aspect—it may, for example, be considered 'awkward', or not easy to carry, and if so a technical improvement which is incorporated in it may be entirely nullified until this limitation is realised and eliminated.

It is generally true to say that a first-rate scientist will have little or no military experience, since men of such calibre were reserved and used in more obviously scientific posts. The converse is also generally true, but on the other hand there is a wide need today for many senior officers to be well qualified scientifically in order to be able to assess both the scientific and military aspects of army problems. (The same applies, of course, to the Royal Navy and the Royal Air Force.)

Lower down the scale there is a still greater need for officers with some regimental experience, as users, to have a good grounding in science to about degree standard. This is true, for example, in the realm of gunnery, particularly in anti-aircraft, and although such arms as the artillery are termed non-technical they are becoming more and more technical due to scientific developments. Still farther down the scale is the great demand for junior officers to teach the principles of equipment to their troops, many of whom, such as radar and signals operators, must have a high degree of intelligence, skill and technical knowledge if they are going to carry out their work effectively.

Most army officers have no knowledge of science beyond what they learnt at school, or during the officer-cadet course at Sandhurst. A small proportion of those who become officers graduated in science before joining the army, but such persons are rare.

The normal entry to a permanent commission in the army is via Sandhurst, where the most promising reach Intermediate B.Sc. standard. The officer cadet passing out of Sandhurst is granted a regular commission and posted to a corps or regiment. If he joins a *technical* corps, he will be given more intensive instruction in science. Until recent years, a limited number of officers (mainly in the Royal Engineers) were sent to Cambridge to take the Mechanical Sciences Tripos, which gave them a general science course lasting two years and including electricity and electronics.

## THE DEGREE COURSE AT SHRIVENHAM

To widen the availability of scientific education in the army, the Military College of Science was formed to cater for the far greater numbers than can be accommodated at Cambridge. Today, on leaving Sandhurst, a young officer who has passed his Intermediate B.Sc. or General Schools Certificate examination at the appropriate level, has the chance of further study for his degree.

All officers of the R.E. and the R.E.M.E., and a proportion of those in Royal Signals, are now expected to obtain degree qualifications in engineering or science. For these the Military College of Science holds courses leading to the London University External B.Sc. degrees in engineering and science. These courses have application not only to the technical corps, but also to the 'teeth' arms—infantry, artillery, etc., whose work is increasingly scientific at a high level and increasingly technical at a low level, so that it will be realised that general and specialised scientific training is very necessary for these arms of the service.

At present all those officers who obtain Inter. B.Sc. qualifications are able to take a two- or three-year B.Sc. degree course at the Military College of Science. Since the M.C. of S. does not hold university status, students take the external degree examination of London exactly as do other external students in colleges which do not award their own degree. This fact is of the greatest importance since it completely upsets the common misconception that army higher education is of a different level from university training.

The Military College of Science is designed for a yearly intake of eighty students on the degree course. An interesting innovation is a 'Direct Entry' scheme designed for schoolboys to obtain regular commissions by doing the normal National Service officer training and a certain time as a regimental officer, followed by a degree course at the College. This entry is designed for the academically 'bright' boy who has passed his London Inter. B.Sc., or equivalent, for whom it offers an early commission and the certainty of a degree education.

At the Military College of Science students live in much the same way as undergraduates at a university. They can wear civilian clothes, and have no routine military duties which might reduce the time available for study. The army aspect is, however, provided in that they have halls run on the lines of the officers' messes in which they normally live during their army career. Instruction is mainly by the civilian academic staff, but the senior military staff includes the directors of study, who are responsible that the courses meet the army's needs. Where necessary, for purposes of practical illustration, army equipment is used; such as an army vehicle engine in connexion with lectures on internal combustion engines; otherwise the instruction and laboratory

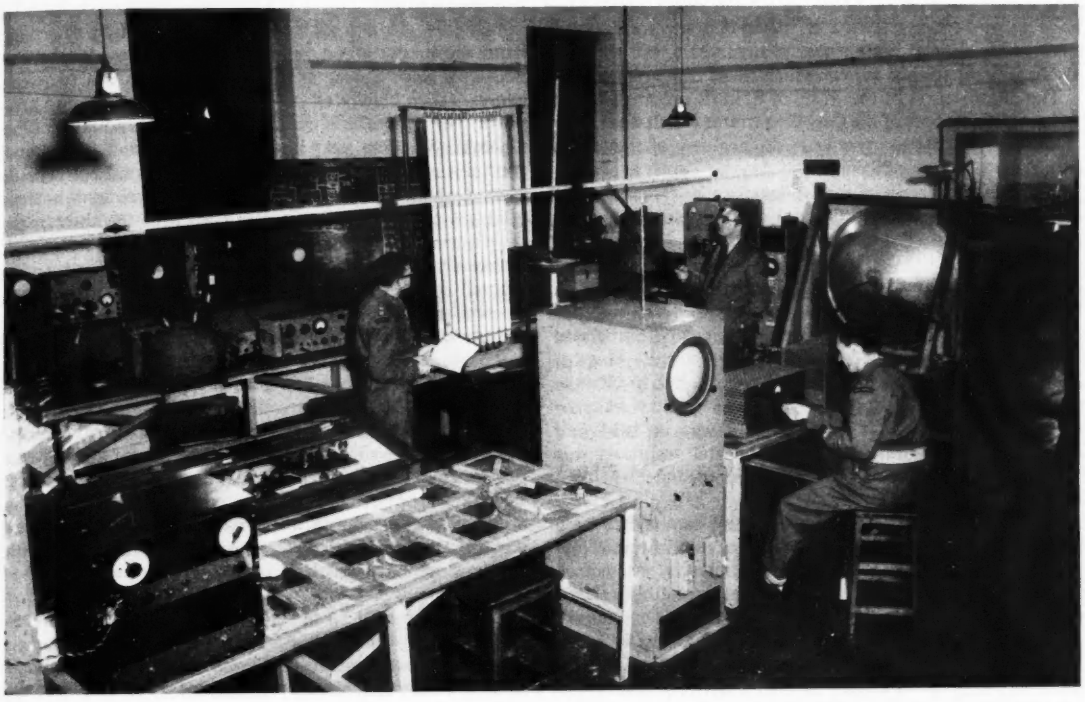


FIG. 1 (*above*). Typical of the well-equipped laboratories at Shrivenham is this laboratory which is used for demonstrating the basic principles of radar and telecommunications.

FIG. 2 (*right*). The academic head of the Military College of Science is Prof. O. G. Sutton, F.R.S. (*left*), who is seen here with the military commandant, Major-General B. C. Davey.

FIG. 3 (*below*). A general view of the college. The vital importance of the function it fulfils was well expressed by the Duke of Edinburgh when he said of the college, "An establishment which teaches science to soldiers and, at the same time, soldiering to scientists, is not an interesting novelty, it is an absolute necessity."

equipment do not differ in essentials from what one finds in universities. Most of these courses are for the engineering degree, taking nearly three years, but there is also a general science course which takes two years.

The organisation of the M.C. of S. in its present form is based on the Report of the Guy Committee which was set up at the end of 1944 to investigate the problem of the future education of army officers.

The ultimate origin of the College can be traced back a long time; some see its starting point in the year 1772, when two young gunnery officers, E. Williams and A. Jardine, founded the Military Society of Woolwich for the theoretical, practical and experimental study of gunnery. This had a varied history, as can be imagined, but eventually it gave rise (in 1885) to the Artillery College. The title was changed and it was called the Ordnance College. Most of its students came from the Royal Artillery, but it did take officers from other corps. The main course was the Advanced Class, but at the outset of war in 1914 and 1939 this course was curtailed, and the emphasis was placed instead on short courses for immediate war-time needs.

The Military College of Science is now established on a magnificent site, at Shrivenham, in the Vale of the White Horse. The buildings it occupies were erected just before the war. These were originally designed to hold all the personnel and equipment of an anti-aircraft brigade, with the result that the College has very abundant space.

The military commandant is Major-General B. C. Davey, C.B., C.B.E. The academic staff is organised under the Dean, Professor O. G. Sutton, C.B.E., F.R.S. The College comprises four main departments, each of which has an academic head with the status of professor; these cover respectively: mathematics and physics; chemistry; mechanical engineering; and instrument technology.

At the present time the College can accommodate more students than are sent to it, but this is due solely to the newness of the organisation. The College laboratories are as well equipped as the best university laboratories. The apparatus is modern and there is sufficient of the commoner variety of instruments to enable many students to work simultaneously on the same experiment. The dark and dim basement laboratory finds no place at Shrivenham: all the laboratories, as well as classrooms, are on or above ground-floor level. Other buildings have been set apart to exhibit a selection of weapons, vehicles, etc., so that their evolution may be traced. These exhibits are primarily intended for post-graduate study, or for visiting officers dealing with particular design problems.

After graduation the young officer is posted by the War Office to some unit or formation where he can acquire more military knowledge and experience. He does not at this stage specialise.

## TECHNICAL STAFF TRAINING

The course described above is an initial or undergraduate course; students who take it tend to be immature and unable properly to appreciate to the full the military significance of all they have learnt at Shrivenham. A further course of training is therefore required for officers of all arms at about the age of thirty, by which time an officer should have had about ten years' service and have a good idea by personal experience of the user's requirements of modern armaments. He will then be in a better position to benefit from more specialised training. This is provided by the *Technical Staff Course* at Shrivenham. This is a two-year course, taken chiefly by captains and majors; a large proportion of its intake is made up of former graduates of the College. The first year is a general one, and the second specialises in one branch as a principal subject with a second as a subsidiary. The successful student is then qualified to a high level in one branch of the three main divisions—weapons, fighting vehicles and fire-direction instruments, and he has a good working knowledge of a second, so that, for example, combined with a thorough knowledge of tanks he also has a useful knowledge of guns for use on tanks, or of guns combined with fire-control instruments. Passing the course leads to the qualification "p.t.s.c." which stands for "*passed technical staff course*".

After qualification, an officer will serve more or less alternately in technical and non-technical appointments. There are other special post-graduate courses at the M.C. of S., mainly arranged for particular purposes; for instance, the course on guided missiles, which attracts not only military officers dealing with this subject but also civilian scientists in the Ministry of Supply who are concerned with the development of such weapons.

## THE ARMY'S TECHNICAL SCHOOLS

For those young officers not able to follow up their scientific education at the M.C. of S. there are army schools serving the various arms of the service. These include the School of Military Engineering at Chatham for the R.E.; the School of Signals at Catterick for Royal Signals, and the R.E.M.E. Training Centre at Arborfield. Qualification at these schools does not lead to a university examination or degree, but it is a corps qualification.

Officers who are unable to take degree courses, either at Cambridge or at the Military College of Science, are catered for by the school of their arm of the service. The teaching here is generally of a practical nature, more obviously applied to military needs. These schools also provide more specialised courses, involving a period spent in civilian factories producing army equipment; the training and subsequent practical responsible experience often leading to Associate Member status of one of the professional institutions. Examples are the long civil engineering course, and the electrical and mechanical engineering course of the R.E., the long telecommunications course of the Royal Signals, and the petroleum technology course of the R.A.S.C.

In addition there are army and command schools; good examples of the latter being the Anti-Aircraft Command School at Lydd, and the Armoured Fighting Vehicles School at Bovington and Lulworth. Each is well equipped to train selected personnel for technical duties, including all other user arms. Although equipment for each is adequate for the purpose, they do not compete with the wider range of apparatus etc., nor do they have the academic staff of the M.C. of S. In addition, there are schools in each main theatre overseas, corresponding generally to army schools, catering for more detailed technical instruction of all arms as required for local needs. These schools are mainly staffed with military instructors, with some civilian staff in lieu of the complement of military instructors.

# CHROMATOGRAPHY PAST AND PRESENT

TREVOR I. WILLIAMS
B.A., B.Sc., D.Phil.

The recent award of a Nobel Prize for research on chromatography provides both convincing evidence of the outstanding importance this method of analysis has achieved and an appropriate occasion for surveying its development and present position. Since chromatography was last discussed in a DISCOVERY article (April 1945), much has happened. Partition chromatography, in the form developed by Martin and Synge, was then still in its infancy; ion-exchange chromatography was virtually unknown, for not until November 1947 was there published, in the *Journal of the American Chemical Society*, a whole series of outstanding papers describing its use in separating some of the fission products, and other substances obtainable only in minute amounts, resulting from various wartime atomic energy projects. Finally, recent studies have called for a complete revision of ideas about the historical development of chromatography and those who effected it.

All available evidence indicates that chromatography had its origin in certain empirical tests, used by workers in the dyeing industry, which certainly date from the early nineteenth century and possibly earlier. The strength and quality of dye-baths were commonly tested by dabbing a little of the liquid on some absorbent material such as cotton; under these conditions the dye spreads outwards and if, as is very often the case, it is not a single chemical individual but a mixture, the various components of the dye may separate in differently coloured rings concentric with the original spot. Besides being useful as a working test, this separation is of practical importance; for example, when printing designs on fabric with mixed dyes.

Towards the middle of the nineteenth century this phenomenon attracted the attention of the German chemist Runge, a specialist in dyes and dyeing and inventor of the first synthetic dyestuff. In place of the cotton fabric of the dye workers, Runge used absorbent paper, virtually identical with modern filter paper, for effecting the separation of the components of mixtures. He fully realised the analytical possibilities of the method—especially in inorganic chemistry—when carried out under controlled conditions, and described a suitable experimental technique in Volume III of his *Farbenchemie* of 1850. Indisputable evidence of his skill in inorganic paper chromatography exists in his published works, many of which are illustrated with actual chromatograms pasted in by hand. The title-page of his very rare *Der Bildungstrieb der Stoffe* is reproduced overleaf; it is illustrated with twenty-two actual chromatograms. Runge, who was as deeply interested in art as in science, also used his method for obtaining artistic effects.

Runge's work was followed up by other nineteenth-century workers. In Britain, T. Bailey investigated the separation of metallic ions, especially cadmium ions, on paper. G. F. Schoenbein and later F. Goppelsroeder, too, carried out elaborate experiments in paper chromatography. Goppelsroeder used strips of paper instead of following Runge's radial method; he published a large monograph on his so-called 'capillary analysis'. Goppelsroeder even tabulated, for a number of substances, what in modern terminology is called the $R_F$ value—that is, the relative rates at which the solvent and the solute travel through the paper. In America, J. V. Lloyd published a paper describing a paper chromatographic technique in 1885. Again, in 1893, L. Reed published accounts of experiments for the separation of organic substances on paper. Grüss, too, carried out most extensive paper chromatographic analyses in the first decade of the twentieth century. Thus, even as early as the end of the nineteenth century there existed what can fairly be termed a voluminous international literature on paper chromatography.

## ORIGIN OF COLUMN CHROMATOGRAPHY

In tracing the origin of another important technique of chromatography—adsorption chromatography on columns—we must again go back fully a century. Runge again claims our attention, for he detailed and investigated the separations which occur when solutions containing several dissolved substances are drawn up into blocks of porous wood. Similar studies were later made by Goppelsroeder, who in addition used columns of such powders as sand or kieselguhr. The basic mechanism of the separations thus effected is obscure, but it may well, especially in the case of kieselguhr, have depended upon differences in adsorptive affinity.

Two British agricultural chemists—H. S. Thompson and J. T. Way—also have some claims to be considered among the originators of column chromatography. About 1850 they published, in the *Journal of the Royal Agricultural Society of England*, accounts of experiments clearly describing the spatial separations which occur when solutions of inorganic substances are passed through columns of certain types of soil. However, Runge and Goppelsroeder had relatively little interest in columns, and Thompson and Way were concerned much more with the movement of dissolved plant nutrients through soil than with techniques of chemical analysis, so their part in the development of column chromatography must be viewed with some reserve. Others who succeeded at an early date in separating substances from solution on adsorption columns were Nasse (1890) and Reed (1893); the latter's work on paper chromatography has already been mentioned.

For unequivocal evidence of the use of column chromatography strictly as a method of chemical analysis, we must look to the petroleum industry, and to the vegetable and animal oil industry. At an early date vegetable oils, such as rape oil, were purified by passing them through beds composed of charcoal or one of the common bleaching earths. It was well known both that successive fractions of the filtrate differed in composition and that there was often some stratification of the impurities retained by the adsorbent. By 1850 shale oil from the Hanover oil-fields was regularly being processed by passage through columns of bleaching earths. In 1886 C. Engler and M. Boehm

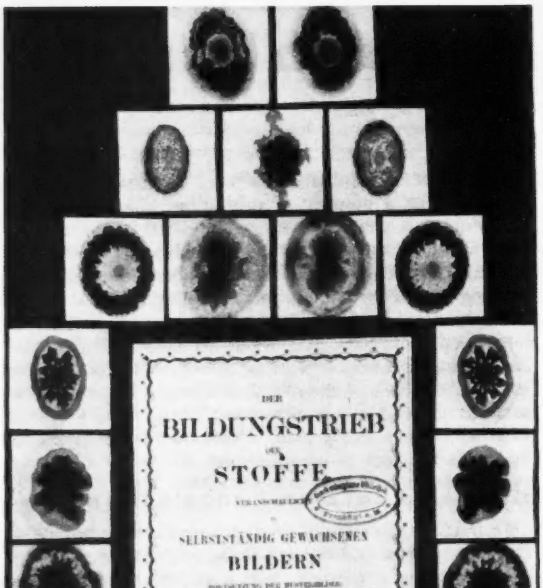

DER
BILDUNGSTRIEB
DER
STOFFE
SELBSTSTÄNDIG GEWACHSENEN
BILDERN
D. F. F. RUNGE.
OranienBurg, 1855.

FIG. 1. Title page of Runge's *Der Bildungstrieb der Stoffe*, illustrated with no less than twenty-two original inorganic paper chromatograms. This rare book thus offers incontrovertible proof that the possibilities of separations upon absorbent paper were well known at least a century ago.

took the technique a stage further and started to use batteries of tall, narrow tubes containing charcoal. Their process enabled them to achieve a considerable purification—the filtrate consisted largely of saturated hydrocarbons while unsaturated material was retained at various levels in the columns.

Meanwhile, interest in petroleum was rapidly increasing in America. There D. T. Day was investigating, among other problems, the origin of natural petroleum in the earth's crust: he was familiar with the work in Hanover and believed that the well-known variations in the composition of petroleum from different sources were connected with the fact that the crude material was altered by being forced through natural deposits of adsorbent minerals. To test his theory he passed crude petroleum through columns of fuller's earth and similar powders, and observed the separations which occurred. He quickly realised, and applied, the immense analytical possibilities of this method, and gave the first detailed account of his experiments at the First International Petroleum Congress in Paris in 1900, where they attracted very wide attention. Their analytical importance was quickly realised and exploited by Russian petroleum chemists, such as Rakusin, W. E. Herr, E. Phyaelae and L. Gurwitsch; in America his method was taken up by J. E. Gilpin, M. P. Cram and others.

In Germany, Engler and E. Albrecht investigated Day's method at once, and as early as 1901 published a paper on the purification of petroleum by passage through a column of Florida earth. Their investigation was most thorough. They collected successive petroleum fractions emerging from adsorbent columns and distinguished them by differences in such physical properties as density, viscosity, and boiling-point. They built a special experimental column with port-holes at intervals along its length so that samples could be withdrawn when desired for analysis. They did not restrict themselves to the analysis of petroleum, but stressed the possibilities of the method in other fields.

It is thus indisputable—for the original publications are available for consultation by anybody interested enough to take the trouble—that at the turn of the century the analytical possibilities of passing solutions through adsorption columns was firmly established and had been described in well-known journals in many different countries. The claims of M. S. Tswett to be the discoverer of column chromatography—which have gone undisputed until recently—must therefore be completely reassessed.

Tswett, as is well known, effected a separation of the principal plant pigments—carotene, chlorophylls and xanthophylls—by passing them in solution in petroleum ether through columns of calcium carbonate and other adsorbents. His first paper, however, was not published until 1903, and his interest in columns was even then limited, his main interest being quite clearly in the use of adsorbents by static methods and not by allowing solutions to flow through them. This 1903 paper, incidentally, was published in Russian in a very obscure journal—the *Journal of the Natural History Society of Warsaw*—and is virtually unknown. Not until 1906, when his much better-known papers were published in German journals, did Tswett fully realise the import of column chromatography and make extensive use of it. Tswett was a cosmopolitan character—born in Italy of an Italian mother, educated in Switzerland and apparently assuming Russian nationality on his appointment to a post in Warsaw—and a competent linguist. It is difficult to believe, in view of the interest they attracted and their wide reporting in the scientific literature, that he was unaware of the experiments of Day, Albrecht, Engler and the other workers mentioned above. If he did know of them, Tswett's failure to refer to these workers is perhaps understandable; as a botanist he was much more interested in the plant pigments he was separating and in their physiological role, than in the actual methods used to separate them. To have quoted the earlier chemical literature would have been analogous, for example, to quoting purely chemical literature about a new dyestuff in connexion with its use for staining botanical sections. While it is possible that Tswett may have been an independent discoverer of column chromatography, it is nevertheless certain that the method, complete in every essential was in use at least three years before his earliest published reference to it.

There is thus a wealth of evidence that chromatography

in both its principal modern forms—analysis upon paper and upon adsorption columns—was perfectly well known and quite extensively practised fully half a century ago. How is it, then, that interest in it lapsed so greatly that today—when chromatography has proved so immensely valuable as to justify the award of a Nobel Prize—this earlier work is virtually unknown and the method is generally regarded as a comparatively modern invention? No satisfactory answer can be given, but the mystery may be partly due to the fact that when the method was originally developed current research problems could not fully utilise its special advantages—notably great sensitivity and absence of effects liable to decompose very labile substances—so that generally recourse was had to conventional methods which, in the particular circumstances of the time, were equally satisfactory.

Interest in chromatography diminished in the first decade of the twentieth century, but it did not altogether die, for some experiments continued, notably in the analysis of petroleum.

Early in the 1930s, however, there arose an experimental problem for which adsorption chromatography provided not merely an ideal solution but virtually the only solution. The problem arose in the investigation of the natural carotenoid pigments, many of which possess vitamin A activity and are thus of the greatest physiological interest. Chemically, however, these substances are difficult to handle and isolate, for they differ so little in chemical constitution as not to respond at all readily to normal methods of separation; moreover, they are so readily decomposed that only the gentlest methods can be used in handling them. However, as even minor differences in molecular structure are reflected in considerable differences in adsorptive affinity, column chromatography came into its own at last. A series of spectacular successes in this important field—initiated by R. Kuhn and E. Lederer—very soon convinced chemists that this long-neglected method of chemical analysis deserved their very close attention. During the last ten years it has in consequence found widespread application in the isolation of such diverse materials as vitamins, natural pigments, antibiotics, hormones, drugs and dyes.

## MARTIN AND SYNGE'S RESEARCHES

This sudden flare-up of interest in adsorption chromatography did not, curiously enough, lead to any general resumption of interest in paper chromatography, which had to wait yet another decade before achieving the recognition it deserved. When it did come, it came not from a belated recognition of the significance of the earlier work but by a new approach to a research problem.

In Leeds, A. J. P. Martin and R. L. M. Synge were investigating the amino-acids of which wool proteins are built, and for this purpose they developed a counter-current extraction process in which amino-acids were distributed between two immiscible solvents (one of them water), moving in opposite directions. Excellent though it seemed in theory, this method proved difficult in practice owing to the impossibility of keeping the two solvents completely separate. To overcome this, they conceived the idea of 'anchoring' the water by means of silica; from water-glass they prepared a silica gel which, although flowing freely as a fine white powder, contained as much as 40% of water.

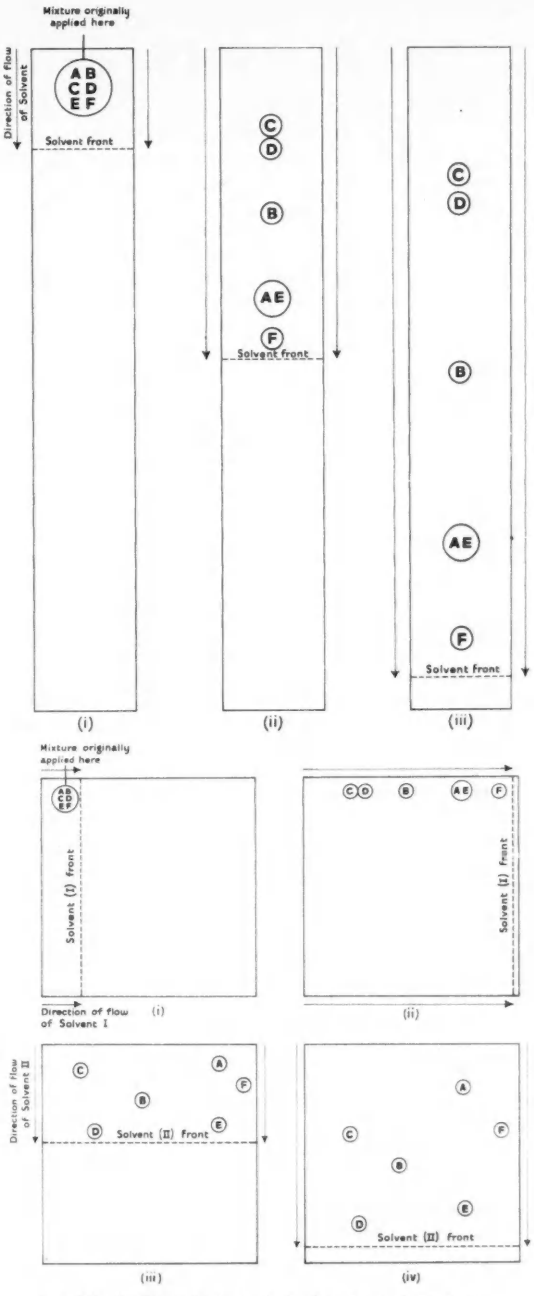



FIG. 2 (*top*). Stages in the analysis of a mixture A, B, C, D, E, F, on a paper strip. Note that the separation of C and D is poor, while A and E remain together throughout.

FIG. 3 (*bottom*). Stages in the analysis of the same mixture, A, B, C, D, E, F, on a square of paper. Stage (ii) corresponds to Fig. 2 (iii). At this stage the paper is dried and treated with solvent II, which flows at right angles to the original solvent I. In this way A and E, which were inseparable before, are brought to quite different points, and the separation of C and D is much improved.

When amino-acid derivatives, dissolved in organic solvents, percolated through columns of this silica gel, the acids separated at different levels, just as substances do on adsorption columns. Although the experimental technique of this type of partition chromatography is thus virtually identical with that of adsorption chromatography the basis of the separation is, of course, quite different.

This technique of partition chromatography* on columns did not, however, provide an analytical method delicate enough to meet the exacting needs of Martin and Synge. They found that the water normally present in absorbent paper—such as filter-paper—is firmly bound and can serve the same purpose as the water in silica gel. Separations can thus be effected on strips of paper in just the same way as on columns of silica gel; in this case the flow of solution is brought about by capillary action (Fig. 2). This method has its limitations, however, for despite its high specificity certain substances nevertheless behave so similarly as to reach virtually the same spot in the chromatogram formed on the strip. This difficulty was overcome by utilising the fact that the rate at which a particular substance progresses depends upon the solvent used. Accordingly, sheets of paper may be used instead of strips, and two different solvents passed across them successively at right angles, the paper being dried between each process (Fig. 3). In this way the components of a mixture can be spread over a whole sheet of paper—perhaps as much as thirty inches square—and very delicate analyses can be effected. Substances brought to the same spot by the first solvent are separated by the action of the second.

Paper partition chromatography as expounded by Martin and Synge had an immediate success, partly, no doubt, owing to the large number of accumulated problems which could be reopened by this one available key to further progress. Its advantages are manifold. It is an exceedingly simple method, requiring no elaborate or expensive apparatus; it is exceedingly delicate, complete analyses often requiring no more than a thousandth of a gram of material; it puts no strain upon easily decomposed substances, within which class are many of the utmost physiological importance; because of its simplicity it lends itself to the making of hundreds, or even thousands, of successive analyses, numbers which would be too laborious to undertake by conventional methods.

The first account of Martin and Synge's paper partition chromatography appeared in 1944; today the method is in daily use in laboratories throughout the world and it is no exaggeration to say that it has profoundly affected the development of many different branches of chemistry. In its original field of protein analysis it has proved invaluable, but its scope is now vastly wider than this. The method has been applied with conspicuous success in the analysis of such varied organic substances as sugars, polysaccharides, phenols, enzymes, fats, vitamins, tannins, hormones and alkaloids. It has, moreover, recently proved of great value in the inorganic field and methods have been worked out for carrying out systematic analyses of all inorganic cations and many anions. These tests are not only simpler and faster than those of the familiar standard methods of group precipitation but require only a fraction of the material usually needed; the tests are now sufficiently well worked out to have been introduced into some normal teaching courses.

Various modifications of the simple paper chromatographic technique have recently been introduced. The most important of these is the so-called 'reversed phase' technique. In this the water in the paper is replaced by some other stationary solvent such as rubber latex or petroleum jelly. It is a method sometimes valuable when the partition of a desired substance between water and an organic solvent does not lend itself to straightforward paper chromatography.

Towards the end of 1947 a third method of chromatography emerged, not as tentative experiments but as a fully fledged and very fruitful method, especially for inorganic substances. This method is known as ion-exchange chromatography, and is based on the simple ion-exchange process widely used for water-softening. If hard water is allowed to percolate through a bed of zeolite or one of the modern ion-exchange resins the 'hard' ions—notably calcium and magnesium—can be replaced by the 'soft' sodium which does not interfere with the lathering of soap. If a long column of ion-exchange material is used different ions can, under suitable conditions, be separated upon it. The full and rapid development of this method was due primarily to various wartime atomic energy projects which demanded a very delicate method for the isolation of minute quantities of fission and other products for detailed chemical, physical and biological examination. It was used also for the large-scale separation of certain metals, notably the rare earths whose similarity of properties makes their separation by conventional methods exceedingly laborious and difficult. It can, indeed, be said that ion-exchange chromatography has completely revolutionised rare-earth chemistry.

Ion-exchange chromatography has also been applied for the separation of gases, especially the inert gases which, having no powers of chemical combination, present peculiar analytical difficulties. It has been used, for example, in the micro-analysis of helium and neon derived from such varied sources as the stratosphere and the occluded gas of meteorites; the latter is of much interest as it paves the way to really reliable estimates of the age of meteorites and, rather unexpectedly, of the intensity of cosmic rays in outer space in former ages.

Lack of space forbids discussion of the great possibilities of chromatography as a unit process in industry, now being very closely investigated and already finding some applications. (See DISCOVERY, December 1950.)

This article has dealt with the past history of chromatography, which has proved very much longer and more extensive than was until recently realised, and with its present applications in almost every possible field of chemistry, applications having indirect repercussions in fields as remote as cosmology. Yet one cannot doubt that the possibilities of the method are far from being exhausted.

*So called because the constituents of a mixture are parted, some going into the water and some into the immiscible solvent.

# METHANE IN THE SERVICE OF MAN

L. T. MINCHIN
B.Sc., M.Inst.Gas E., M.Inst.F.

Methane is one of the more romantic of the substances which are to be met with in the school chemistry books. In introducing it the authors usually unbend a little—taking the schoolboy straight out of his classroom for a moment and allowing him to indulge, in fancy, in that fascinating pastime of stirring up marshy ponds with a stick. A typical text-book entry reads:

> "It rises to the surface when the bottoms of marshy pools are disturbed with a stick, and it issues from the seams in coal beds."

Reading further, the schoolboy learns that methane is produced by "the decomposition of vegetable matter in absence of air . . . In many regions it is confined, like the oil, beneath impervious strata and is forced out through borings by hydrostatic pressure. It is found mainly in or near the localities where oil is found."

Methane, which has the formula $CH_4$ and is structurally as simple as any organic compound, has considerable theoretical interest, being the first member of the large family of hydrocarbons known as paraffins. Moreover, it is economically important, being a valuable fuel; it has in addition potentialities as a raw material on which to base the large-scale synthesis of organic compounds. (Such synthesis is not easily done direct from methane, which first needs to be converted into a more reactive substance like ethylene or acetylene.)

Methane is a relatively light gas, having a density 0·55 that of air.

For millions of years huge amounts of methane have been liberated by decaying organic matter, and large quantities must also have found their way into the atmosphere from underground coal- and oil-bearing strata. It would be a fascinating study to consider where all this methane has gone to, for it is not a normal constituent of the atmosphere, yet being very stable chemically, it is not easy to see how it has been destroyed. However, that is not within the scope of the present article. We are here concerned to discuss the various sources of methane which are of commercial importance, and the methods by which they are used or could be used in the future, for the service of man.

## NATURAL GAS

Much the most important source of methane today is the natural gas which comes from oil-bearing sandstone in many parts of the world. In the early days of oil-drilling in the United States, borings were often found to produce no oil but only methane at high pressure. Sad to say, they were often left to spout the gas into the atmosphere, for its potential usefulness was not realised at the time. A great deal is indeed wasted even now in the Middle East, simply because there is no useful commercial outlet in the neighbourhood. In the U.S.A., however, methane has come into its own, and is widely used as a domestic and industrial fuel. A phenomenal series of long-distance high-pressure pipe-lines have been built to convey the gas all over the sub-continent, some of them—such as the ones from Texas to New York—being well over a thousand miles long.

For a geological formation to function as a reservoir in which natural gas can accumulate it must have certain characteristics. This can be appreciated by reference to Fig. 1. An essential feature is that an impervious layer must lie above the oil-bearing sandstone, and this must be so shaped that it traps the oil and gas. The commonest way in which these can occur is as a 'dome' (Fig. 1a), but it can also happen that a geological fault will form a reservoir in a similar way (Fig. 1b). The substance yielded by an oil-field can include the whole range of paraffin hydrocarbons—from methane, a permanent gas, through propane and butane (liquefiable gases) to the motor spirit components, kerosene, heavy oil and pitch. Sometimes, however, the wells only yield methane (with a little ethane)—known as 'dry gas'—or 'wet' if the liquefiable paraffins are present.

The occurrence of natural gas under the soil of a country is an economic asset and often of the greatest importance. In the U.S.A. energy consumption per head is the highest of any country in the world, and three-fifths of it comes from natural gas. The price of gas over most of the country makes it as cheap, or cheaper, to use than raw coal.

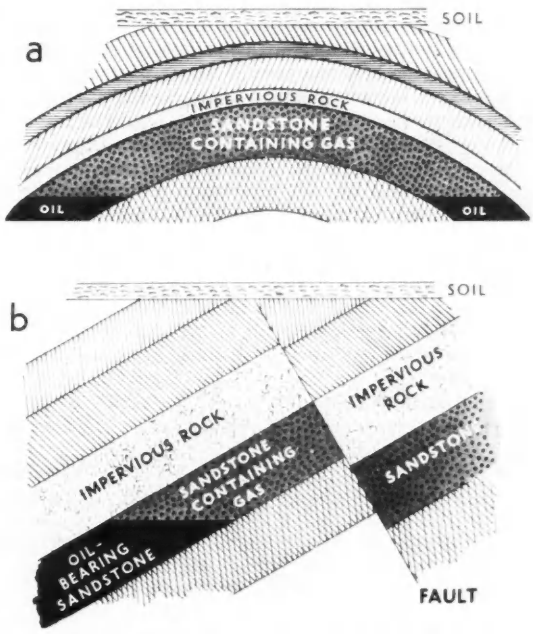



FIG. 1. Diagrammatic sections of the earth's crust showing two of the ways in which natural gas is trapped in rocks: (a) shows a 'dome' or anticline; (b) shows gas trapped by a geological fault.

and this means that, for example, central heating by gas, is one of the cheapest ways of heating a house. (In Britain central heating by coal gas is something of a luxury!) Fig. 3 shows the general plan of the gas pipe-lines in the U.S.A. which carry methane from the gas wells in the south and on the Pacific Coast to the big centres of population.

In Alberta, to the north-west of this map, very big reserves of gas are now being exploited, and they may in the future supply part of the northern United States (e.g. Seattle). A trans-Canadian pipe-line to carry the Alberta gas to Toronto and the other eastern cities is already under active consideration. It is safe to say that these gas-fields will have a great and lasting effect on the development of the country, especially as even bigger reserves have been found in the region of the Peace River, on the borders of northern Alberta and British Columbia.

Since the war there has been a considerable amount of natural gas found in Europe, and Italy in particular has benefited greatly from this. This is a country which has always laboured under the heavy handicap of having practically no good mineable coal, and having to import a great deal. This disadvantage may well be wiped out as the production of natural gas develops. The four principal gas-fields (all lying south-west of Milan, in the Po valley) are expected to yield 200 million cubic feet of methane per day—equivalent to about 10,000 tons of coal. Pipe-lines are being laid as rapidly as possible, and the west coast of Genoa will probably be linked up with the east coast at Venice by the time this article appears in print. Another country poor in coal which expects to gain great advantage from natural gas is Holland. In the north-eastern part of Holland (Ober-Ijssel province) near the German border extensive reserves have been found, but have not yet been exploited on any scale. At Bentheim, in Germany, just the other side of the frontier, gas has been made use of for some years. France, Hungary and Austria also have gas wells that are proving extremely useful.

As for Britain, there seems no reason to suppose that very extensive gas-fields will ever be discovered here, but in North Yorkshire, near Whitby, serious drilling is being undertaken at the moment. It seems likely that if successful the gas obtained will be used to supply the new Wilton works of I.C.I. with fuel.

## GAS FROM COAL SEAMS

Methane seems to be one of the main gaseous products formed when organic matter decomposes, and this is true whether the decomposition is by bacterial fermentation (as takes place at the bottom of a pond) or by the slower processes which over millions of years have produced coal and oil in the earth's crust. Indeed, the first process in the formation of coal from wood is a peat-like substance, and this will be formed largely by bacterial decomposition. Under geological pressures, and moderate heat, this slowly turns to lignite, or brown coal, then to black coal, and finally anthracite and even graphite.

Each stage in the long evolutionary process of coal formation and maturation corresponds to an increase in the percentage of carbon, and a fall in the percentage of oxygen. It is generally agreed that in this process various gases are split off as by-products at each stage: for example, carbon dioxide, hydrogen, methane, and ethane ($C_2H_6$). Hydrogen will be rapidly lost by diffusion, and carbon dioxide will react with basic rocks to form carbonates. Methane, however, remains in very large quantities, compressed in the pores of the coal and of the rock above and below it. As the coal is cut away, and as fresh roads are made into the rock, this gas finds its way into the air of the mine, largely through the thousands of fissures which develop in the 'roof' of the workings.

For the past hundred and fifty years the history of coal-mining has been one long fight against this gas, and nearly every one of the fires or explosions underground that has marred the history of the industry was caused wholly or in part by methane. More and more powerful fans have been brought into operation, and the control of the path of the

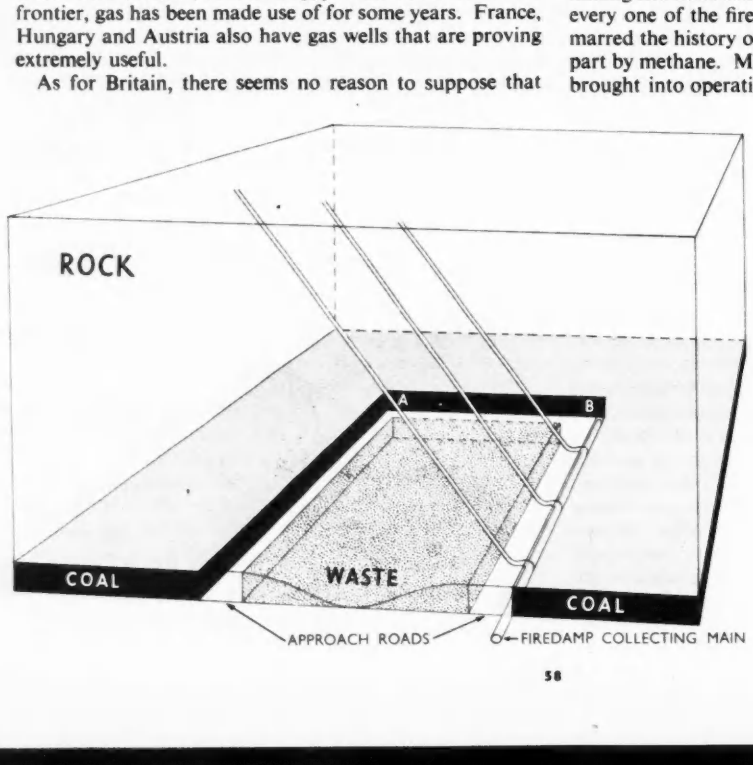



FIG. 2. A portion of a coal mine, shown as though it were modelled in transparent plastic. Coal is being won from the face A-B and gas is being drawn from the three boreholes which project from the roof of the right-hand approach road diagonally over the 'waste' (from which coal has been removed).

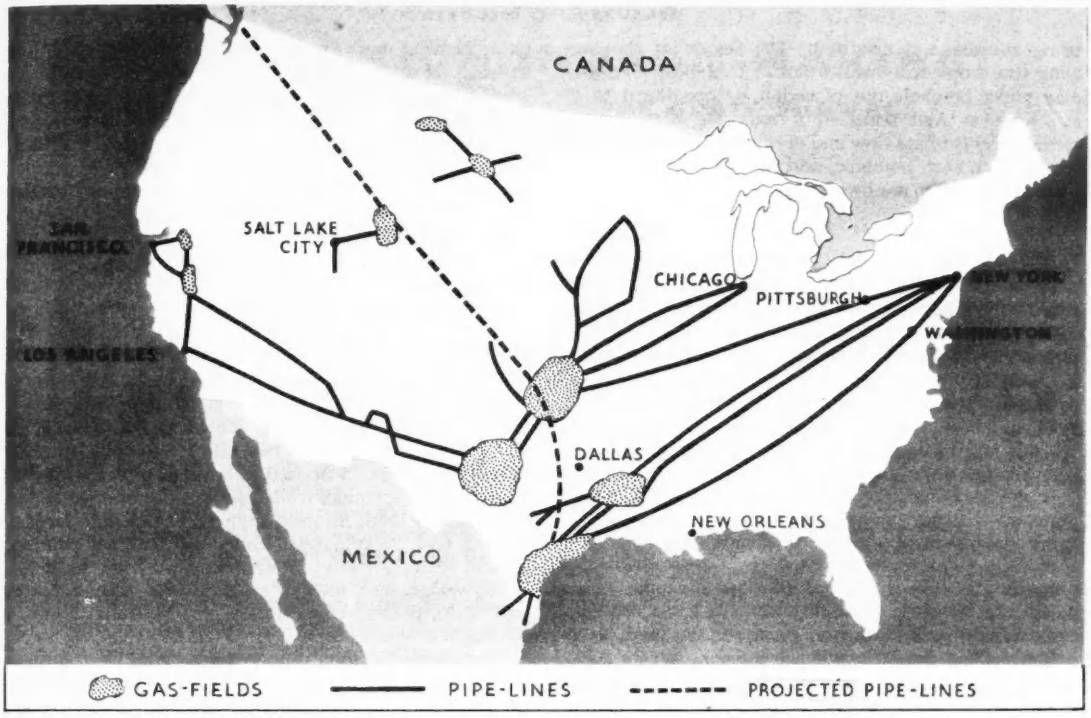



FIG. 3. Map showing some of the principal pipe-lines for conveying natural gas in the U.S.A.

ventilating air has been made more precise, but in spite of these precautions the ventilating air from a coal-mine quite often has as much as 1% methane in it. This concentration is well below the inflammability limit of methane in air, and from the safety angle this may be regarded as reasonably satisfactory. From the point of view of fuel economy, this dilution of the methane by the ventilation method leads to the wastage of valuable fuel. A really gassy mine will blow into the atmosphere several million cubic feet of methane in the course of a day, or the equivalent of perhaps 100 to 200 tons of coal.

Of recent years a new process has been developed which is usually known as 'methane drainage', and this is remarkable for the fact that at the same time it achieves two desirable ends; it makes the mines safer and it provides a supply of relatively pure methane at the pit-head which is capable of being used as a fuel or, if need be, a chemical. Not all the methane liberated by a mine can be trapped in this way, of course; no matter how thoroughly the method is carried out, the galleries and coal face must be ventilated, and the ventilation air comes out carrying a reduced but still substantial percentage of gas.

## DRAINING THE COAL SEAMS

There are various ways in which methane drainage can be put into operation, but Fig. 2 is a schematic representation of the commonest method. This shows what might be a block model in transparent plastic of a portion of a mine, with several layers of rock above the seam. The seam in this case is a horizontal one, and it is being worked by the 'longwall face' method. Each day a slice 2 to 3 feet thick is taken off the coal face by a machine or men working between A and B, so that the working surface recedes farther back each day. In the space from which coal has been removed, the rock sinks down till floor and ceiling touch, thereby depressing all the strata which lie above it.

A certain amount of gas is emitted at the actual coal face, but the coal is not sufficiently porous here (being in a state of intense compression) and far more gas finds its way up into the overlying strata from the virgin seam and then appears again in the roof of the 'waste' or of the galleries. To drain the gas from these overlying strata is therefore the main task of the engineer, and in the diagram three boreholes are shown which start from the roof of one of the roads and extend at about 45 degrees to the horizontal across the 'waste'. These boreholes are normally about 200 feet long and 3 inches in diameter, and at the lower end they are carefully cemented into the rock for 20 or 30 feet. A rubber hose leads from them to the collecting main shown in the right-hand road, and from here the gas is led up to the surface. A slight suction—one or two inches of water column—is applied to the collecting main, but if this is increased too much the percentage of air in the firedamp will rise unduly.

As the coal face recedes, fresh boreholes will be drilled perhaps 20 or 30 feet apart, and as the distance between borehole and face increases the gas yield falls off. Eventually the hole will yield so little gas that it can be blocked off, but all the while newer holes are being brought into use as the old ones come to the end of their useful life. It is not perhaps realised by the reader unused to mining conditions that in front of a coal face the rocks are continually

being stressed and distorted. The flexion of the overlying strata obviously causes cracks to appear, and these may put a borehole out of action by opening it to the air, however well sealed-in it may be. Consequently measurements of gas flow and of pressure have to be made regularly on each borehole, and records kept, so that the man in charge can see how each one is behaving.

## WHAT THE GAS IS USED FOR

The system of methane drainage we have just described is being employed in Britain to an increasing extent, but it is to the Continent that we have to look for the best examples of planned utilisation of firedamp. The Saar territory and Belgium are the two pioneer countries, though it is only fair to point out that the first mine in the world to employ it was a German mine in the Ruhr district in 1943, and but for the disorganisation in the post-war years it is probable that the main advances would have been centred round the Ruhr district.

In the Saar, and more particularly in Belgium, there is quite an elaborate grid system for picking up the methane from one coal-mine after the other, and this means that supplies are far more constant as regards quality and quantity than they would ever be from one mine. It also means that methods of dealing with the gas which entail some capital expenditure on plant can be used, as the volume of gas available is much greater. Where such a network does not exist, the usual practice is to use the gas for firing the colliery boilers and providing water for the pit baths—sometimes steam for power. This, however, is not ideal usage, for there will normally be plenty of poor-quality coal at the pit-head which can be burnt under boilers but is not worth transporting. Methane is normally worth more as a refined fuel—one which can be cheaply transported by pipe-lines and burnt under accurately controllable conditions.

One thing must be made clear at this point—firedamp cannot be used as a straight substitute for ordinary towns gas; not, at least, unless radical alterations are to be made to every burner in the area of supply. Methane burns much more slowly than coal gas. If one attempted to use pure methane on a cooker, shall we say, designed for towns gas, the flames would leave the burner, rise up into the air and vanish. In order to make it suitable for use in such cases, the methane must be partially decomposed by reacting it with steam and (usually) oxygen; for instance, either

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

which needs a considerable supply of heat to promote it, or

$$2CH_4 + O_2 \rightarrow 2CO + 4H_2$$

which is exothermic, and gives out heat. A catalyst is usually used, especially for the first reaction.

This 'cracking' or 're-forming' process is used extensively for natural gas both in Europe and in the United States, but only one plant in the world so far is operating on firedamp. This is situated at St. Aldegonde in Belgium, in between Mons and Charleroi, at the centre of a network of pipes specially laid to collect methane from eighteen collieries. The gas is fed into this catalytic cracker and enough methane is by-passed and added at the outlet to give the final gas similar properties to ordinary towns gas.

It is possible that methane may one day become important as a chemical, but it seems that in European conditions at least, its value as a fuel is likely to be greater. In the southern States of the U.S.A., however, natural gas is so cheap that it is used on quite a large scale for carbon-black manufacture. At one factory in the Ruhr natural gas is used to make ethylene, and from this poly-ethylene plastics. A factory to make Polythene from the same raw material is being built in Canada. Firedamp, however, normally contains about 20% of air, and this makes it less suitable as a starting-point for chemical manufacture. Should it ever be used for that purpose, acetylene is most likely to be the first stage in the process.

## SLUDGE GAS

There is one other source of methane which must be mentioned; that is, fermentation gas from organic wastes, and particularly from sewage. To get this, one makes use of a process known as the 'sludge-digestion' process, which was originally devised as a means of converting the noxious waste-product from a sewage disposal works into a sludge which had no smell and could be used for fertiliser or as a fuel. In cylindrical tanks like small gas-holders a special bacterial culture is allowed to work on the sewage waste sludge, and not only is the sludge made odourless but the methane formed can be piped off and used as a source of power.

The sludge-digestion process is now used to a considerable extent, and a new plant is being installed at Barking by the L.C.C. at this moment. At most of the modern sewage works in the country methane generated in this way is being used as a source of power for making electricity and sometimes for raising steam. Moreover, their vehicles are converted to use methane instead of petrol, and in some cases the very considerable heavy transport needs of the works are met in this way.

This is a field which, we may safely say, is by no means fully explored. Large amounts of methane could be obtained from kitchen waste; some experiments in Germany recently have shown that 1 kilogram of dry rubbish will give between 200 and 700 litres of gas when subjected to anaerobic fermentation. Factories have been set up to obtain fermentation gas from not only kitchen waste but also some industrial wastes; the waste from a yeast factory, and the residue from a beet-sugar factory, have both been utilised in this way, for example. Even stable manure has been treated in this way; the yield of gas is not quite so high, but the solid residue is an even better manure than the original material.

Probably the subject will never be completely explored; for it seems safe to predict that as long as civilisation lasts we shall go on finding fresh ways of making something useful from what was before a waste product. It is certainly one of the most attractive applications of science, and so long as the present world hunger for fuel and power lasts (and no end is predictable at the moment), methane, the gas which you can stir up from the village pond, will be a much-prized commodity.

### READING LIST

Report of Working Party of National Coal Board and Ministry of Fuel, "Drainage of Firedamp from Mines" (1951).

"Methane from Coal Mines", L. T. Minchin. *Coke and Gas*, March–May 1952.

# A REVOLUTION IN IRON-MAKING?

## OXYGEN ENRICHMENT AND THE BLAST FURNACE

MAX DAVIES
B.A.

The iron-making blast furnace is one of the oldest pieces of industrial apparatus in use. Men have used it for about 600 years. In that time it has grown in stature from a height of 6 ft. or 8 ft. to round about 100 ft. Its output has increased from a ton or two of iron per day to 750–1000 tons. In all these metamorphoses, however, the basic principles on which it works have not been altered. The changes have, in fact, been very largely of an engineering nature—Watt, for example, liberated the iron-maker from dependence on water power for raising the wind. The price the blast furnace has had to pay for these advances has been increasing dependence on particularly high-grade supplies of fuels and other raw materials. As these threaten to run short—the threat is a reality in some parts of the world—there appears a likelihood of the modern giant furnace being once more truncated to something like the size of its predecessor of a century ago. This may be accomplished, however, without loss in efficiency, and with the prospect of making possible the exploitation of some hitherto uneconomic deposits of iron and low-grade coals and lignite.

### PRINCIPLES OF BLAST-FURNACE OPERATIONS

The blast furnace is an apparatus for extracting the iron from iron oxide, the form in which the element usually appears in nature. Although the chemistry by which this is effected is quite complex, it is based on a perfectly straightforward reaction, which the whole of the process is directed to promoting and regenerating:

$$FeO + CO \rightarrow Fe + CO_2.$$

This reaction is initiated by violent combustion of coke in a blast of hot air (hence the term 'blast' furnace) which generates carbon monoxide. This gas comes into contact with iron oxide in the ore (which is mixed with the coke as the 'burden' of the furnace), and as the combustion raises the whole to a sufficiently high temperature, reaction between the ore and carbon monoxide takes place. Molten iron is produced and separates out, to trickle down the furnace, past the combustion zone, gathering in the 'hearth' at the bottom of the shaft, whence it is withdrawn ('tapped') at intervals.

Clearly it would be advantageous to use the sensible heat of the carbon dioxide thus generated, and this the blast furnace arranges in the simplest possible manner. The raw materials approach the combustion zone by moving slowly down a high stack above the zone, up which the gas passes before being piped off through cleaners into other parts of the works. Fig. 1 shows how the gas gives up its heat in the course of its passage up the stack.

The sequence of chemical reactions that this arrangement makes possible is neat, and from the iron-making point of view, singularly effective. Carbon monoxide is regenerated from the carbon dioxide by the reaction:

$$CO_2 + C \rightarrow 2CO.$$

The carbon which effects this reduction comes, of course, from the coke. As the newly formed CO passes up the stack it again reacts with the iron oxide in the ore; the $CO_2$ thus formed in its turn reacts with coke, and forms CO and so on and on until the top of the furnace is reached, where the gas emerges with approximately this composition:

| | |
|---|---|
| CO | 30% |
| H | 1–3% |
| $CO_2$ | 10% |
| N | remainder |

For the full record, it must be mentioned that this is a highly simplified account of a fairly complex process. In all charges, for example, a certain amount of calcium oxide is present, either in the ore or added as limestone. This forms a slag with the silica in the ore to make calcium silicate, which may also contain phosphates and sulphates. Further, the iron oxide in the ore is usually in the form $Fe_2O_3$, which has first to be reduced thus:

$$Fe_2O_3 + CO \rightarrow 2FeO + CO_2.$$

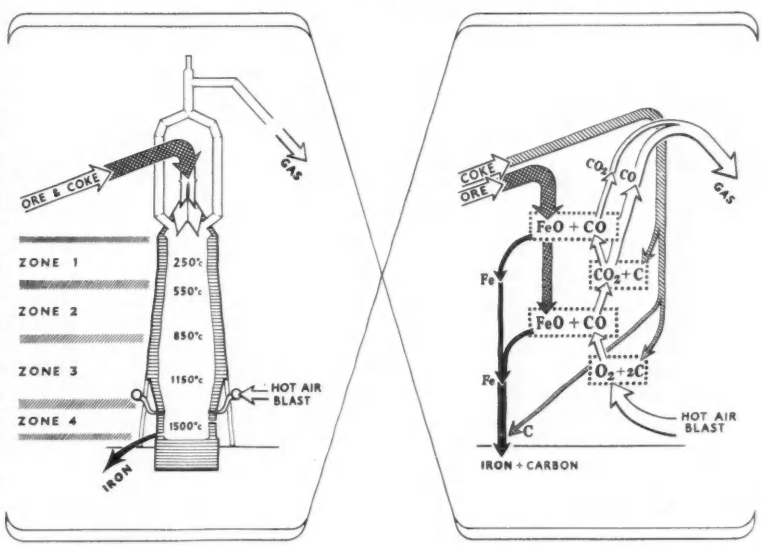



FIG. 1. Blast furnace temperatures and reactions.

The general principles, however, are legitimately comprehended in the form given above.

It will be seen that the device of a tall stack makes for thermal efficiency, though it is not essential to the process. In favourable circumstances a modern blast furnace combined with a steelworks in an integrated plant reaches a high level of thermal efficiency. By conserving the heat in the iron (by bringing it molten to the steelworks); by burning the blast-furnace gas in heat-regenerating stoves and elsewhere; by using the slag for roadmaking materials or building blocks, the combined unit can be brought up to a thermal efficiency of 90–95%.

The high stack, however, makes the furnace vulnerable in that it puts a heavy load on the materials carrying the weight of the burden in the stack. At and just above the combustion zone this may amount to a load of about 1 ton per sq. ft. Consequently, the furnace can only use ore and fuel which are both porous and strong. These essentials are the Achilles heel of the iron-making industries throughout the world.

To meet the mechanical and chemical requirements of the furnace, most ore is crushed to an appropriate size, and fines are screened off and sintered with coke fines. The porous nature of this agglomerate, and the intimate mixture it promotes of the burden constituents, make it particularly acceptable, and the tendency is to use more and more sinter in blast-furnace burdens. Not every type of ore, however, is suitable for sintering.

For fuel the blast furnace demands 'metallurgical' coke, which is particularly hard and porous. At the present time the iron industry of Great Britain is using 11,000,000 tons of metallurgical coke annually. By 1957 the demand will be 17,000,000 tons per year. Both the N.C.B. and the iron industry are countering a potential shortage by increasing blending research and facilities (as in a new coal-blending plant at Messrs. John Summers' works at Shotton). But more fundamental answers may be wanted in the long run.

Three awkward problems, in fact, are beginning to press for attention:

(i) There are indications that existing supplies of coking coal may not be sufficient to keep pace with increased demands for blast-furnace coke.

(ii) There is a growing demand for the establishment of iron-making capacity in areas far removed from deposits of coal.

(iii) Established centres of iron-making are having to use more and more finely divided, soft and low-grade ores.

While these factors are not likely to lead to entire replacement of conventional blast furnaces by a new apparatus, it is very likely that a proportion of new construction will be specially designed to cope with them, particularly with the need to use other fuels.

The problem is to construct and operate a furnace with a shaft short enough not to crush the burden at the bottom, however weak the fuel may be, but long enough to use the up-going gases to a sufficient extent to ensure thermal efficiency. Such furnaces are called 'low-shaft' blast furnaces. These are of three types: electric furnace, low-shaft furnace using oxygen-enriched blast, and low-shaft furnace using briquetted charges (which may or may not use enriched blast).

*Electric low-shaft blast furnaces* are established pieces of plant, and have been used for the production of pig iron and ferro alloys for about 50 years in Scandinavia, and more recently in Switzerland and northern Italy, where good ore and low-cost hydro-electric power are available but coke is not. Power consumption at 2500 kWh per ton makes the method economic if power can be supplied at about 0·1*d.* per kWh. The cost in this country is about 0·75*d.* It is possible, however, that in India and Africa, where hydro-electric power is being developed on a large scale, the electric blast furnace will have possibilities.

*The low-shaft blast furnace with oxygen enrichment* is still an experimental apparatus. Fränkl's discovery of a method of making slightly impure oxygen cheaply in the early 1930s stimulated a fair amount of work on oxygen enrichment of the blast of ordinary furnaces. Tests at

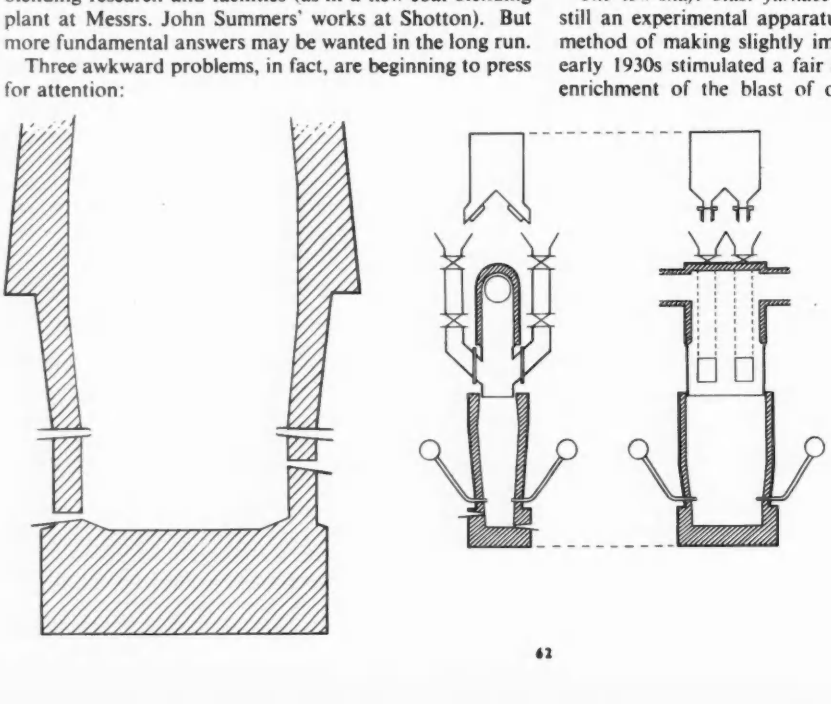


FIG. 2. Profile of a low-shaft blast furnace for 60–80 tons per day production. For comparison, a section of a normal blast furnace drawn to the same scale is shown.

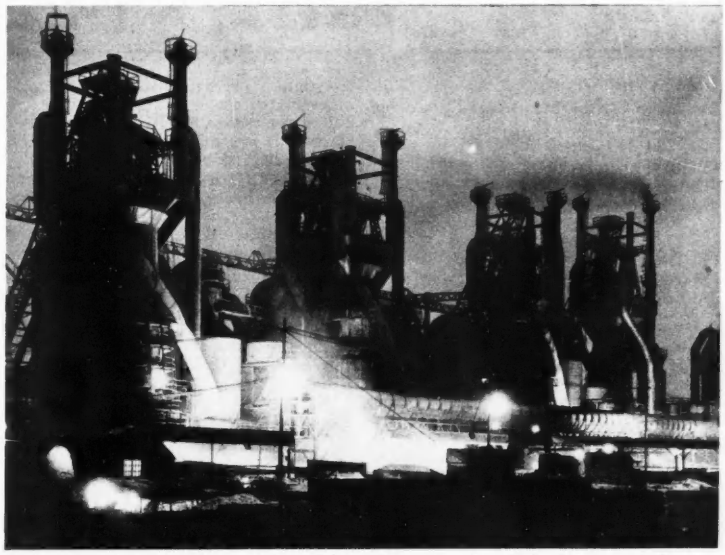


FIG. 3. A battery of conventional blast furnaces at Corby, Northants. (*Courtesy, Stewarts and Lloyds Ltd.*)

Oberhausen in the Rhineland in 1933, and elsewhere later, led to the general conclusion that even with this cheap source of gas, enrichment could not justify itself economically, largely because the increase in production was only small and the iron was liable to go 'off grade'.

Recent work, however, has suggested that success might be attained if an oxygen-enriched blast were applied to a furnace with a stack height reduced to accommodate low-grade fuel.

If carbon in the blast furnace is burnt with oxygen-enriched air instead of normal air, the quantity of gas passing up the stack per pound of carbon burnt will be less, and the conditions in the furnace are altered in two ways. First, the furnace can burn coke faster. This is because the amount of wind accepted by a furnace is controlled by the flow-resistance of the burden. With enriched air less nitrogen needs to be forced through the furnace per pound of coke burnt. Second, with oxygen enrichment the available heat per pound of heating coke is at a higher temperature, and this will promote direct reduction which will consume the heat available in the combustion zone. For this reason a proportionately smaller amount of low-temperature heat will be available for stack reaction. There will be a steeper temperature gradient in the stack, and a high shaft becomes unnecessary.

Prospects are sufficiently promising to interest the O.E.E.C., who have expressed alarm at the gloomy prospects of European coke and ore supplies. Trials are in progress at the works of the Société Anonyme Ougrée Marihaye in Liège, Belgium, financed by international contributions through the O.E.E.C. and guided by a committee of experts set up by this body. Great Britain is represented as an associate member on this committee by the British Iron and Steel Research Association, and limits its participation at present to advice and technical assistance if called on. This reflects the lower degree of urgency with which this country views the problems.

The furnace has just come into production. It has an elongated oval hearth, measuring 9 ft. 9 in. × 4 ft. and has 8 tuyères.* Vertical side walls reach 16 ft. 6 in. from tuyères to stock line, giving a height to average hearth diameter ratio of about $3\frac{1}{2}$ to 1—about half the normal. Provision has been made for operation at high top pressure up to $2\frac{1}{2}$ atmospheres. The unit will produce about 60 tons of iron per day with normal blast; more if blast enriched with 30% or more of oxygen is used. Up to 50 tons per day of oxygen is available from the nearby works of the Societé Belge de l'Azote.

Fig. 2 shows the profile of a similar though not identical furnace described in *The Iron and Coal Trades Review* (Sept. 26, 1952).

At first, Minette ores from Lorraine will be used with ordinary metallurgical coke, while the minimum particle size of burden which is practicable is being discovered. Then oxygen enrichment of blast will be tried, and tests will also be made to find out what happens when the furnace is charged with lower-grade ore, poor-quality coke, etc. and when operating conditions are changed in other ways.

*The low-shaft blast furnace with briquetted charges* uses ore, fuel and flux powdered, mixed and pressed into shape with a binder. This brings the components of the charge into such intimate contact that mechanical reactions can take place more easily and a long downward travel is unnecessary.

One furnace with a shaft some 14 ft. high and 3 ft. square is in experimental operation in a works in Cologne. Here pig iron has successfully been produced from low-grade German ore and lignite, and also from various manufacturing residues, and an unwashed bituminous coal. At the moment fuel consumption is high, in the region of 2 tons of coal per ton of iron. But a very rich gas is produced which in certain circumstances might be considered the main product from unpromising materials, the iron being a valuable but incidental by-product.

* A tuyere is a nozzle through which air is blown into a blast furnace.

# Far and Near

### Night Sky in February

*The Moon.*—New moon takes place on Feb. 14d 01h 10m, U.T., and full moon on Feb. 28d 18h 59m. The following conjunctions with the moon take place:

| February | | | | |
|---|---|---|---|---|
| 5d 18h | Saturn in conjunction with the moon | Saturn | 8° | N. |
| 16d 23h | Mars ,, | Mars | 5° | S. |
| 17d 09h | Venus ,, | Venus | 2° | S. |
| 19d 14h | Jupiter ,, | Jupiter | 6° | S. |

*The Planets.*—Mercury is in superior conjunction on Feb. 2 and is not well placed for observation till later in the month; the planet sets at 18h and 19h 15m on Feb. 14 and 28, respectively, and soon after the middle of the month is visible in the evening. Venus is an evening star, its times of setting at the beginning, middle and end of the month being 21h 05m, 21h 35m and 21h 50m, respectively. The stellar magnitude is about −4·2 and the visible portion of the illuminated disk varies between 0·51 and 0·34.

Mars can be seen in the early evening hours, its times of setting being 20h 50m approximately throughout the month. Its stellar magnitude is 1·3, and in the early portion of the month it is a little south of λ Piscium; its eastward movement amongst the stars brings it south of ε Piscium at the end of the month. Jupiter sets at 1h 15m, 0h 25m and 23h 45m on Feb. 1, 14 and 28, respectively. Its stellar magnitude varies from −2 to −1·8 and at the end of the month it lies a little south of δ Arietis. Saturn rises at 23h 40m on Feb. 1 and at 21h 55m on Feb. 28; its stellar magnitude averages 0·7 during the month and it lies a little north-east of Spica which is not quite as bright as Saturn.

There will be a partial eclipse of the sun on Feb. 13–14, which will not be visible at Greenwich. It begins in the Pacific Ocean, west of Mexico, and ends a little south of Bear Islands, Siberia.

### Britain's U235 Factory

The success of British scientists and engineers in solving the practical problems of plutonium production received well-deserved publicity after the explosion of the Monte Bello bomb, the explosive charge for which was prepared in the Windscale factory at Sellafield in the Lake District. At the turn of the year came news of another success to the credit of the production side of the Ministry of supply's atomic energy division. Factory production of uranium 235, it was announced, has started ahead of schedule in the £10 million plant at Capenhurst in Cheshire. This factory, according to a press report, is due to reach its maximum output in 1956.

### Atomic Work Recognised in New Year Honours List

The New Year Honours List included the names of several scientists connected with the atomic energy programme, a fitting recognition of the outstanding progress made in Britain in this field in 1952. A C.B. was awarded to Mr. R. Spence, chief chemist at Harwell, and a C.B.E. to Mr. C. J. Turner, chief engineer in the Risley unit of the Ministry of Supply's Atomic Energy Division. O.B.E.s went to two M.O.S. scientists engaged on atomic energy work—Mr. G. L. Hopkin and Mr. I. Maddock. The assistant works manager of the Windscale plant, Mr. T. A. Parry, received an M.B.E.

On the scientific side of the Monte Bello tests Dr. L. C. Tyte was second-in-command to Sir William Penney, and he was awarded a C.B.E. in the Honours List.

* * *

The most exclusive honour which the monarch can bestow on a British scientist is an O.M., for the membership of this order never numbers more than twenty-four. The one O.M. awarded in this New Year was conferred on Dr. Wilder Graves Penfield, who has been Professor of Neurology and Neurosurgery at McGill University, Montreal, since 1934.

### New Technical College Specialises in Aeronautical Engineering

Training in aeronautical engineering is a special feature of the Hatfield Technical College, Herts. which was officially opened by the Duke of Edinburgh on December 16. There are courses, for example, to prepare students for the Royal Aeronautical Society's examinations, while special attention is being paid to the establishment of courses for aircraft maintenance engineers and aircraft electricians. This particular bias, which is explained by the existence of large aircraft factories in the neighbourhood, has not been allowed to interfere with the College's function as a polytechnic, and it provides courses in many other subjects.

### Aircraft Industry's Co-operative Wind Tunnel

Work is well ahead on the £1¼ million high-speed wind tunnel. It was started at the beginning of 1952 as a co-operative venture by fourteen aircraft firms who formed a company to operate it, the Aircraft Research Association Ltd. Detailed plans are now being finished; its construction should begin early in 1953, and will take about two and a half years to complete.

The primary object of this tunnel will be tests on the wings, fuselage, etc., of particular aircraft right from the early project stage up to the point where they are fully proved in flight. The tunnel will run at speeds of up to 1000 m.p.h. Its maximum section will be 30 ft. by 40 ft.

### Ancient Finds Shed Light on Corrosion Problem

Information obtained from examination of iron implements 2000 years old may lead to a new method of protecting underground pipes from corrosion. Although the articles were buried in one of the most aggressive soils possible, they were found to be perfectly preserved. Small quantities of tannates in the soil appeared to have completely prevented action by sulphate-reducing bacteria, which are responsible for most cases of rapid corrosion in waterlogged clay soils.

The iron articles, ranging from hobnails to knives, were found during excavation by the Ministry of Works Inspectorate of Ancient Monuments on a site at Hungate, York. Normally, on such a waterlogged site, they would rust very rapidly. Because of their exceptionally good state of preservation, samples of the soil in which they had been buried were sent to the Chemical Research Laboratory. Sulphate-reducing bacteria were found to be present but not active. Scrapings from a Roman knife were examined chemically and it was found that there were traces of tannate in the little surface corrosion that existed.

The soil on the site was peaty and contained many leather cuttings. Several medieval shoes were also found and a number of knives which may have been used in the working of leather. (It is believed that in the Middle Ages a Cordwainer's Hall stood near by and that the area was the centre of a leather industry.) Tannin from the leather was evidently instrumental in suppressing the corrosion.

Cultures were made of sulphate-reducing bacteria and inoculated with soil from the site. Their activity ceased if more than 5% was added. This result suggested that extracts from the leather were at least partly responsible. Other experiments using solutions made from the leather itself confirmed this.

Later work has shown that tannic acid in greater concentration than 0·01% stops the action of sulphate-reducing bacteria. The discovery may result in a method of protecting water and gas pipes, for example, from corrosion.

### Books on Physics and Mathematics

The latest in the series of catalogues of scientific books issued by H. K. Lewis & Co. Ltd. (136 Gower St., London W.C.1) is a 52-page booklet giving very full lists of works dealing with mathematics, statistics, physics, astronomy and meteorology.

### Gas Turbines for Royal Navy

Two new types of gas turbine engine suitable for propelling fast coastal vessels have been developed by British firms for the Admiralty. The first of these—the Rolls Royce RM 60—is designed solely for development purposes and will be given sea trials this year.

The other is the G2 turbine made by Metropolitan-Vickers Electric Co. Ltd., which represents an advance on the Gatric model which in 1947 was installed in the Navy's motor gunboat M.G.B. 2009 to make it the first ship in the world to be propelled by a gas turbine

The horse-power developed is 4500, as against 2500 for the Gatric model. Its gas generator (compressor, combustion chamber, compressor turbine, etc.) is based on that of the Beryl jet engine.

**28-year-old Physicist appointed to Fuchs's Post**

Mr. Brian Flowers has been appointed acting head of the theoretical physics division at Harwell. He has been on the staff of the Atomic Energy Research Establishment since 1946, but has spent two of the intervening years doing nuclear research at Birmingham University. He is 28 years old.

This important Harwell post became vacant in 1950, when Klaus Fuchs was arrested and gaoled for spying, and has remained vacant until Mr. Flowers' appointment.

**New Fish Research Station**

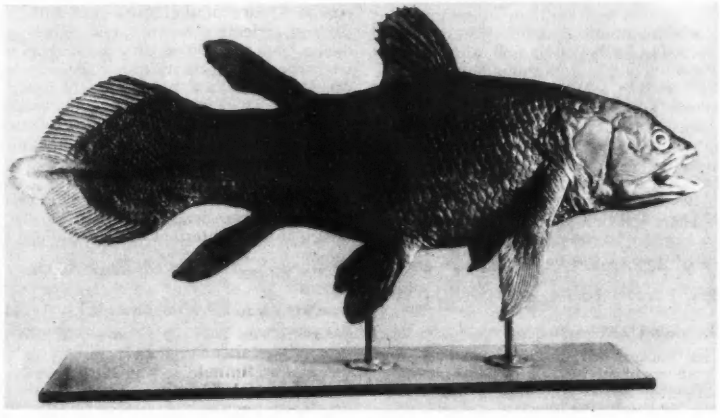
The DSIR has opened a new laboratory which will carry out research on the processing and preservation of fish. Known as the Humber Laboratory, it is situated at Hull and will do for English fisheries the kind of work that has been done in Scotland by the Torry Research Station at Aberdeen, of which laboratory it is an off-shoot.

The secretary of the DSIR, Sir Ben Lockspeiser, in his speech at the laboratory's official opening, stressed the importance of scientific work in this field, giving force to his argument by citing the fact that Britain does not make full use of its fish resources. The country eats less fish than before the war, in spite of the meat shortage. He said this trend in fish consumption is contrary to the national interest, which requires that we should depend more, not less, on fish for our animal protein. "People will not eat fish, willingly, unless it reaches them in good condition, fresh or processed; and this raises questions of refrigeration, storage and curing. We should be wise, therefore, to make up our minds to do whatever we can to ensure that the whole of the catch, obtained with much cost in capital and labour, and all too often in human life, is landed in good condition and reaches the public, fresh or processed, in high quality. This is no easy task, and to enable science to lend a hand we are opening this new laboratory at the Humber."

**Conductive Rubber**

Rubber has been used for so long as an electrical insulator that the discovery that it can be made conductive without affecting its other physical properties came as something of a surprise. Today conductive rubber is important for a number of particular applications; for example it is used for making aeroplane tyres. In flight the fuselage of an aircraft often becomes highly charged with static electricity. Unless this is discharged to earth immediately on landing, sparks may occur during refuelling, which can easily lead to an outbreak of fire. The fitment of one conductive rubber tyre eliminates this hazard, by

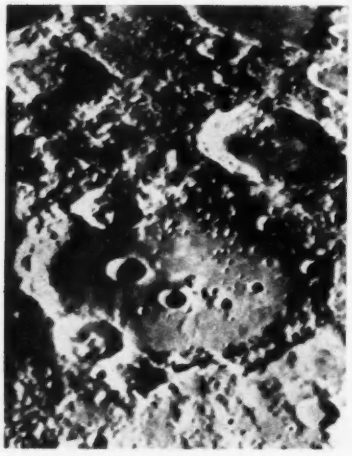
*Prof. Smith with the specimen of* Malania.



*A museum cast of the* Latimeria *caught in 1938.*

**Malania—A Living Fossil**

The order of fishes known as Coelocanths were thought to have been extinct for about 60 million years, until a living specimen was caught in a trawl in December 1938 off East London, Cape Province. This was examined by Prof. J. L. B. Smith, research professor of ichthyology in Rhodes University, who named it *Latimeria chalumnae*. Prof. Smith reasoned that coelocanths might be found off Madagascar, where many fossil remains have been found, and fishermen have been on the lookout ever since. On 20th December 1952, a second living coelocanth (about 5 ft. long and 100 lb. in weight) was caught on a line by a native fisherman, off the island of Anjouan 200 miles west of Madagascar. The capture was reported to Prof. Smith who was flown out to collect it in a S. African Air Force plane put at his disposal by the Prime Minister, Dr. Malan. It proved to be of an entirely different species and has been named *Malania anjouanae*. The specimen is reasonably well preserved and should reveal details of the internal structure of coelocanths which have previously been obscure.



*THIS MONTH'S COVER PICTURE*

*Some of the first photographs of the Moon taken with the 200-inch telescope of the Palomar Observatory have just been released. The large crater known as Clavius is shown in our cover picture. This is 145 miles across and its walls are about 12,000 feet high. The pits in its floor may have been made by meteors, but are more probably of volcanic origin.*

discharging any accumulation of static electricity immediately the wheels touch down on landing. Conductive tyres for aircraft are made with an electrical resistance of less than 100,000 ohms.

The conductive character depends on the incorporation in manufacture of carbon black, the particles of which are arranged in a chain formation.

In an article in the latest issue of *Rubber Developments*, P. D. Patterson gives details of this and other applications of this special type of rubber.

The accumulation of static electricity by cars and buses can lead to passengers getting shocks when they are getting on or off the vehicles. This effect can be eliminated by fitting tyres made of slightly conductive rubber (known as non-static), which finds use in hospital operating theatres where the risk of electric sparks can carry the risk of explosion if the atmosphere contains the vapour of an inflammable anaesthetic.

The article also mentions how non-static rubber has solved what at one time was a puzzling service failure on tyres. They became deflated as a result of punctures in the tube, for which no apparent cause could be found. Investigations in England, Canada and Germany established the mechanism of this occurrence, so that it can now be reproduced at will in the laboratory and corrective measures devised.

The mysterious punctures were found to be due to the accumulation of static charges on the surface of the tyre. These lead to surges in voltage as the tyre rotates, and an alternating current set up between tyre tread and wheel flows along the inner surface of the cover. This current usually passes through any internal paint films put on the tyre cover during manufacture. Where flexing of the tyre causes minute cracks in these paint films, the alternating current jumps the gap in a silent discharge. This discharge does not, in itself, damage the inner tube, but it generates ozone from the surrounding air and, as is well known, ozone attacks rubber very rapidly. This local generation of ozone being concentrated over a small area of rubber under tension soon causes a crack, which eventually develops into a perforation of the tube wall.

It has been shown that the fitting of non-static tyres completely eliminates this type of failure.

# THE BOOKSHELF

**Antoine Lavoisier** by Douglas McKie (*London, Constable, 1952, 335 pp., 30s.*)

This is a fascinating book which gives a full account of the life of Lavoisier, and also provides an excellent picture of Lavoisier's contemporaries in the chemical world and of the impact of the Revolution on French academic life.

Lavoisier spent most of his childhood in a street now mainly occupied by the famous market of Les Halles. Following family tradition he qualified as a lawyer, but while studying for his legal examinations, he still found time to attend the classes of de Lacaille (the astronomer and mathematician), Jussieu (the botanist), Guettard (the geologist) and Rouelle (the chemist). He began to record the readings of his barometer each day, and persuaded his friends in different parts of France and even in other countries to do the same, believing that if enough such records could be obtained it would be possible accurately to forecast the weather—an event only brought to fruition after his death. It soon became apparent that Lavoisier was more fitted to science than to the law.

His father, realising his scientific bent, arranged for him to have immediate access to the income left him by one of his relatives before he legally came of age, and Lavoisier started his full-time career of science. In order to secure his income he took the fatal step of buying a share in the Tax Farm—an organisation run as a private company to collect the taxes of the realm. (It was this that led to his execution in the Revolution.)

On his election to the Academy, he found himself involved in a mass of public work, for the Academy functioned not just as a learned society, but also as a research organisation and a bureau of public standards. Soon yet another public office, the Gunpowder Commission, was loaded on to his shoulders. Not content with all these activities he also turned a part of his estate at Fréchines into an experimental farm.

His classical experiments on air and fire, oxygen, heat and respiration, the composition of water, and his researches connected with his public offices, like those on gunpowder and nitre, are clearly described—and they are set against the background of contemporary work. It is not perhaps surprising that one gets rather tired of the word 'historic' in such a book.

The tragedy is that his non-scientific activities cut short his life so soon. His colleague Lagrange spoke his epitaph on the day following his death—"only a moment to cut off that head, and a hundred years may not give us another like it". But even had he never been connected with the Tax Farm, it seems unlikely, on reading his life, that so active and versatile a person as Lavoisier could have avoided offending in some way, the rulers of the French Revolution.

**Parasitic Animals** by Geoffrey Lapage (*London, Cambridge University Press, 351 pp., 21s.*)

THE phenomenon of parasitism is given plenty of attention even in elementary zoology courses, in which life histories of specific parasites are frequently used to illustrate important biological principles which the young student needs to understand thoroughly before he proceeds to more advanced work. A considerable amount of detailed knowledge about parasite organisms has to be acquired later not only by intending medical students and veterinary students, but also by the student taking a zoology degree. For all these classes of reader this book will be valuable. It covers a very wide variety of parasitic animals, but it is not a text-book of economic parasitology, being designed to emphasise the fundamental biology of parasites rather than their economic importance. The book is well written and abundantly illustrated. It will recommend itself to the many who have read with interest Dr. Lapage's many contributions to DISCOVERY.

**The Molds and Man** by Clyde M. Christensen, 1951. (*Minnesota University Press: London, Geoffrey Cumberlege, 244 pp., 21s. net.*)

THIS VOLUME is a mixture of good and not so good. It is intended as a basic text-book for students of mycology, and as a source of information for persons whose work is affected by the activities of the fungi. The fungi are described as active, living things, the biological aspects of mycology being kept in the foreground, while morphology and systematics take a back place. This emphasis on the living fungus is most welcome. The matter ranges over a wide field, few if any of the topics which are of current interest to mycologists being overlooked. But the points are sometimes taken up too briefly, and, as few references are given to other published work, the reader is not guided so thoroughly as might seem to be desirable. There are a

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few misprints, none serious, and a few minor inaccuracies: the explanations of some of the systematic names could cause raised eyebrows. With the exception of the picture of *Monotropa uniflora*, the illustrations are of indifferent quality, and one of them (Fig. 1) may be fairly described as misleading.

I have not enjoyed the sprightly flippancy of much of the text. Even in a book entitled *The Molds and Man*, the treatment is much too anthropocentric. It seems unwise to describe the fungi in such a way as to suggest that what they do, they do on purpose; for all we know, they may do that, but we do *not* know. Nor do I believe that the fungi are as strenuous in their activities as the text so often suggests. They can grow fast, and they can act fast, but that is no reason for presenting them as creatures which 'get around' in the manner of tourists in a hurry. I do not think that the progress of mycology is helped by an approach which is sometimes reminiscent of the methods of the composers of comic strips, and I do not understand why Professor Christensen has chosen to cover his wide and wide-awake knowledge of mycology under a mountain of froth.

A comparison with E. C. Large's *Advance of the Fungi* is unavoidable. Large writes in a light style, and he does not cover so much ground as does Professor Christensen. But he provides a more satisfying picture. We are not well off for modern books on the fungi, which the general reader can enjoy. Ramsbottom's little book, *Fungi: An introduction to mycology*, is unfortunately out of print, and we still wait, with impatient anticipation, for his promised contribution to the New Naturalist series.

British readers of *The Molds and Man* will glean from the book much general and up-to-date information about the fungi; it may well be that readers younger than I am will not find the style as trying as I have done. The book should be understandable by anyone who has had but a slight training in botany, but I will not try to guess what the non-scientific reader will make of it. University students in this country who have examinations to pass may well use the book as a beginning, but they will have to do much additional reading, and they should be wary of imitating its style. E. BARNES

**An International Bibliography on Atomic Energy, Vol. 2, Scientific Aspects** (*New York, United Nations Publication: London, H.M.S.O., 1951, 75s.*)

**An International Bibliography on Atomic Energy, Vol. 2, Scientific Aspects, Supplement 1** (*New York, United Nations Publication: London, H.M.S.O., 1952, 25s.*)

Volume 2 of the International Bibliography on Atomic Energy is intended to cover the scientific aspects of the subject, and in fact covers most subjects that have anything to do with radioactivity. It consists of about 25,000 references, classified according to subject, and presented alphabetically within a particular subject according to the initial letter of the first author's name; an author index is also provided. The book covers the literature up to the end of 1948 and the supplement of about 8000 references brings the survey to the end of 1950.

The only way of reviewing a bibliography of 33,000 references is to use it for a serious literature search and then to consider whether or not it has inspired confidence in its accuracy and usefulness. Three questions should be considered:

1. Is the bibliography complete and accurate and is it repetitious?
2. Is it easy to cover the literature of a particular field of research?
3. Can an individual reference, which is only partly known, be found and verified?

This bibliography measures up well to the first question; the reviewer has not noticed many important omissions, nor has he found inaccuracies in volume and page numbers. Quite a number of entries appear twice, and many appear both in the main volume and the supplement. Although this is a little irritating, it is not a serious fault.

Without any doubt, the classification into subjects is much better done in this bibliography than in all but one of the well-known series of abstracts. Of course, a smaller field is being covered, but it does appear that each paper has been read and

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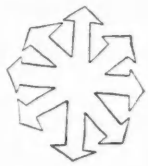

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classified according to its contents irrespective of whether the title is adequate or not. Too often, abstract bureaux produce sound summaries of papers, but because of a poorly chosen title, the paper appears indexed under a classification which gives little clue to its contents.

Verification of a reference is often quite rapid with the bibliography, as a result, no doubt, of the careful subject classification.

Most of the titles of papers are in English, with some in French or German, but other Western European languages are represented. Russian and Japanese references have translations into English or German.

The Bibliography can be recommended to anybody conducting a literature search in the fields which it covers. It should certainly not be the only reference system consulted, but might very well be the starting point of the search.

W. J. ARROL

**Fleming: discoverer of penicillin** by L. J. Ludovici (*London, Andrew Dakers Ltd., 1952, 223 pp., 15s.*)

The general public associates only one name with the discovery of penicillin—that of Alexander Fleming. The names of Howard Florey and Ernst Chain, the two men who, quite independently and long after Fleming had virtually abandoned penicillin, initiated the research which first demonstrated its absolutely unique properties, are almost unknown outside scientific circles. Happily the Nobel Committee, in selecting the prize-winners in 1945, recognised the facts and justly shared the award for medicine between the three principals.

While none would wish to detract from the credit popularly given to Fleming for the initial observation in a truly great discovery, there are many who would like to see the names of Florey and Chain equally honoured. It is, therefore, a pity that in compiling this present work the author did not take the opportunity of putting the penicillin story in its proper perspective, for the facts are now readily accessible to any serious student; the works he admits to having consulted with regard to the history of penicillin are, however, no more than popular accounts which make no claim to being historical studies. What he does not make clear is that, in limited trials with crude material, Fleming satisfied himself of the possibilities of using penicillin for local infections; the contribution of Florey and Chain was to isolate this very easily destroyed drug, which had quite eluded both Fleming and Raistrick, and to show it to be a chemotherapeutic agent *par excellence* against a wide range of pathogenic infections attacking the body as a whole.

However, the discovery of penicillin naturally forms only a part of this biography, which recounts Fleming's life from childhood, and there is much else to describe—his early experience in a shipping office, his decision to read medicine at St. Mary's, where he came under the influence of Almroth Wright and was drawn into the famous opsonin episode, and military service in the First World War, when his forceful views on the treatment of infected wounds were sometimes controversial. On resuming research at St. Mary's he was soon to make a major discovery, that of the remarkable bacteriolytic enzyme lysozyme which, although throwing important light on the natural defences of the body, was disappointing as a practical adjunct to medicine. Then, in 1928, came his important observations of the formation of an antibacterial substance by the mould *Penicillium notatum*, an observation which years later was unexpectedly to bring him fame beyond measure. His later work concentrated on the study of a variety of synthetic antiseptics and chemotherapeutic agents and on problems of natural immunity, reverting to penicillin after the startling discoveries of Florey, Chain and their collaborators at Oxford in the early years of the war.

TREVOR I. WILLIAMS

**Common Farm Weeds Illustrated** (*London, Butterworths Scientific Publications, 1952, 172 pp., 15s.*)

This book (which was prepared by D. L. W. Scovell of Plant Protection Ltd.) is composed of pairs of photographic illustrations, each pair of which shows a common weed in its seedling stage and in its mature stage. It is intended for the benefit of people without much botanical knowledge who need to identify plants, and should be of use to, say, farmers who are concerned whether a particular crop of weeds can be destroyed by spraying with a selective weed killer. The photographs are well reproduced, and coupled with the verbal descriptions which accompany them, they will serve their purpose very well.

**The Essentials of Fluid Dynamics** by L. Prandtl (*London, Blackie, 1952, 452 pp., 35s.*)

The origins of this book lie in a science handbook to which Prandtl contributed in 1913. There are therefore fifty years of work and thought distilled into this volume by a master. His period covers the whole of the modern science of aerodynamics during which, as Director of the Kaiser Wilhelm Institut für Strömungsforschung, he provided a formidable inspiration to German aeronautics. For advanced students in any field of engineering this book will be required reading. It will tax the reader, however; its style is stiff and the book is full of footnotes and unfamiliar symbols. It shines with care and honesty; for instance, we are even asked not to talk of the Prandtl number since this was foreshadowed by Reynolds, although independently deduced by Prandtl later on.

To produce a book of this standard and length, not to mention 343 illustrations, at the price is one of the mysteries for which we must be grateful.

F.E.W.

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